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㉓ A method and composition for increasing the accumulation of squalene and specific sterols in yeast.

㉔ A method of increasing the accumulation of squalene and specific sterols in yeast comprising increasing the expression level of a structural gene encoding a polypeptide having HMG-CoA reductase activity in a mutant yeast having single or double defects in the expression of sterol biosynthetic enzymes is provided. The expression level of a structural gene is preferably increased by transforming yeast with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes a polypeptide having HMG-CoA reductase activity and a promoter that is suitable for driving the expression of the encoded polypeptide in the transformed yeast. The polypeptide having HMG-CoA reductase activity is preferably a truncated, active HMG-CoA reductase enzyme. Recombinant DNA molecules useful for transforming yeast and mutant yeast transformed with such recombinant DNA molecules are also disclosed.

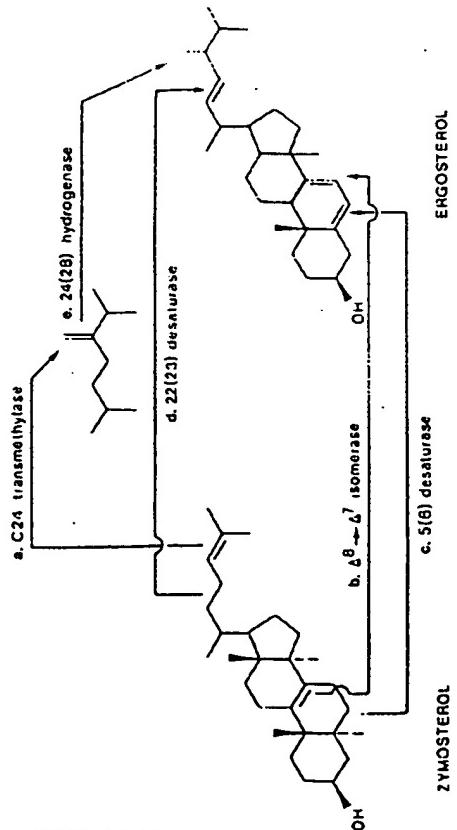


FIGURE 1

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Technical Field

5 The present invention relates to a method and composition for increasing the accumulation of squalene and specific sterols in yeast. Squalene and sterol accumulation is increased by increasing the expression level of a gene encoding a polypeptide having HMG-CoA reductase activity.

Background of the Invention

10 As used herein, the term "sterol" refers to derivatives of a fused, reduced ring system, cyclopenta-[α]-phenanthrene, comprising three fused cyclohexane rings (A, B and C) in a phenanthrene arrangement, and a terminal cyclopentane ring (D) having the formula and carbon atom position numbering shown below:

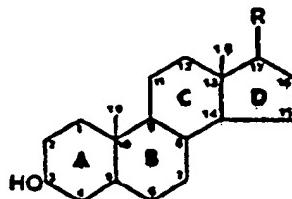


Table 1

	<u>Sterol</u>	<u>Required* Enzymes</u>
5	1. zymosterol (cholesta-8,24-dienol)	none
10	2. fecosterol (ergosta-8,24(28)-dienol)	a
15	3. episterol (ergosta-7,24(28)-dienol)	a,b
20	4. ergosta-5,7,24(28)-trienol	a,b,c
25	5. ergosta-5,7,22,24(28)-tetraenol	a,b,c,d
30	6. ergosterol (ergosta-5,7,22-trienol)	a,b,c,d,e
35	7. ergosta-7,22,24(28)-trienol	a,b,d
40	8. cholesta-7,24-dienol	b
45	9. cholesta-5,7,24-trienol	b,c
50	10. cholesta-5,7,22,24-tetraenol	b,c,d
55	11. ergosta-5,7-dienol	a,b,c,e
60	12. ergosta-7,22-dienol	a,b,d,e
65	13. ergosta-7-enol	a,b,e
70	14. ergosta-5,8-dienol	a,c,e
75	15. ergosta-5,8,22-trienol	a,c,d,e
80	16. ergosta-8,22-dienol	a,d,e
85	17. ergosta-8-enol	a,e
90	18. ergosta-8,14,24(28)-trienol	a

* Enzymes theoretically required for the synthesis of the designated sterol.

Despite the lack of substrate specificity, one might expect that specific alterations in the sterol biosynthetic pathway would have predictable consequences. Currently available data show that such predictability is not

pres nt

For example, mutant *S. cerevisiae* with a defect in the expression of zymosterol-24-methyl-transferase (enzyme a), which mutants are designated erg6, might be expected to accumulate sterols 1 and 8-10 of Tabl 1, which sterols theoretically do not require the action of enzyme a for their synthesis. Parks et al., CRC Critical Reviews in Microbiology, 6:301-341 (1978), however, report that erg6 mutants accumulate only zymosterol (#1), cholesta-5,7,24-trienol (#9) and cholesta-5,7,22,24-tetraenol (#10). Bard, M. et al., Lipids, 12:645-654 (1977), on the other hand, report that erg6 mutants accumulate only sterols #1 and #10.

5 Mutant *S. cerevisiae* with a defect in the expression of ergosta-5,7,24(28)-trienol-22-dehydrogenase (enzyme d), designated erg5, might be expected to accumulate sterols 1-4, 6, 8, 9, 11, 13, 14, 17 and 18. Parks et al., CRC Critical Reviews in Microbiology, 6:301-341 (1978) report, that erg5 mutants accumulate only ergosta-5,7-dienol (#11), ergosta-5,7,24(28)-trienol (#4), ergosta-8,14,24(28)-trienol (#18) and episterol (#3). In contrast, Bard et al., Lipids, 12:645-654 (1977) report that erg5 mutants accumulate zymosterol (#1), ergosta-5,7-dienol (#11), ergosta-5,7,24(28)-trienol (#4), ergosta-7,24(28)-dienol (#3) and ergosta-8,14,24(28)-trienol (#18).

10 Still further, mutant *S. cerevisiae* with a defect in episterol-5-dehydrogenase (enzyme c), designated erg3, might be expected to accumulate sterols 1-3, 7, 8, 12, 13 and 16-18. Parks et al., CRC Critical Reviews in Microbiology, 6:301-341 (1978) report that erg3 mutants accumulate only ergosta-7,22-dienol (#12), ergosta-8,22-dienol (#16), ergosta-7,22,24(28)-trienol (#7), fecosterol (#2) and episterol (#3).

15 These data, taken together, show that specific defects in the expression of one sterol synthetic enzyme do not lead to predictable changes in sterol accumulation. A similar degree of unpredictability is found when sterol accumulation is examined in mutants having two defects in enzymes of the sterol biosynthetic pathway.

Thus, for example, erg5-erg6 double mutants (defects in enzymes d and a) might be expected to accumulate sterols 1, 8 and 9. Parks et al. and Bard et al., above, report that erg5-erg6 double mutants accumulate only zymosterol (#1) and cholesta-5,7,24-trienol (#9).

20 These data relating to sterol accumulation in yeast show that specific alterations in enzyme activity do not result in predictable changes in sterol accumulation. The data further show a lack of agreement between different investigators studying identical alterations. The present invention furnishes a solution to the problem of unpredictability by providing a method and composition for increasing the accumulation of squalene and specific sterols in yeast.

Summary of the Invention

The present invention generally provides a method of increasing squalene and specific sterol accumulation in mutant yeasts having a single or double defect in the expression of sterol biosynthetic pathway enzymes.

35 This method comprises transforming such mutant yeasts with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes a polypeptide having HMG-CoA reductase activity and a promoter suitable for driving the expression of HMG-CoA reductase in the transformed yeast.

The structural gene encoding a polypeptide having HMG-CoA reductase activity preferably encodes an active, truncated HMG-CoA reductase enzyme, which enzyme comprises the catalytic and at least a portion of the linker region that is free from the membrane binding region of HMG-CoA reductase enzyme. The copy number of the structural gene is increased by transforming a mutant yeast with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes a polypeptide having a HMG-CoA reductase activity and a promoter that is suitable for driving the expression of the encoded polypeptide in the transformed yeast.

40 Suitable promoters include promoters that are subject to inducible regulation by factors either extrinsic or intrinsic to yeast. Preferably, both the promoter and the exogenous DNA segment are integrated into the chromosomal DNA of the transformed yeast.

The present invention most preferably provides a method of increasing squalene, zymosterol, cholesta-7,24-dienol and cholesta-5,7,24-trienol accumulation in yeast of the species *S. cerevisiae* comprising increasing the expression level of a structural gene encoding a polypeptide having HMG-CoA reductase activity in a mutant *S. cerevisiae* having defects in the expression of zymosterol-24-methyltransferase (erg6) and ergosta-5,7,24(28)-trienol-22-dehydrogenase (erg5).

In further preferred embodiments, transformation of a mutant yeast having a defect in the expressi n of the enzyme episterol-5-dehydrog nase (erg 3) results in a transformed, mutant yeast which veraccumulates squalene, ergosta-8,22-dienol, ergosta-7,22-dienol, ergosta-8-enol and ergosta-7-enol. Transformation of a mutant yeast having a double defect in the expression of zymosterol-24-methyltransferase and episterol-5-d hydrogenas enzymes (erg6 and erg3) results in a transformed mutant yeast which overaccumulates squalene, zymosterol and cholesta-7,24-dienol. Transformation of a mutant yeast having a defect in the exp-

ression of ergosta-5,7,24(28)-triol-22-dehydrogenase (erg 5) results in a transformed mutant yeast which overaccumulates zymosterol and a mixture of ergosta-5,7,24(28)-triol and ergosta-5,7-dienol.

Transformation of mutant yeast is preferably accomplished using a recombinant DNA molecule selected from the group of plasmid vectors consisting of plasmids pSOC725ARC, pSOC106ARC, pARC306E, pARC300D, pARC300S, pARC300T and pARC304S. Most preferred is plasmid pARC304S.

The present invention further provides for a mutant species of *S. cerevisiae*, which mutant has a double defect in the expression of zymosterol-24-methyl-transferase and ergosta-5,7,24(28)-triol-22-dehydrogenase enzymes (erg 5 and erg8). That mutant *S. cerevisiae* is designated ATC0402mu.

The present invention still further provides for a mutant species of *S. cerevisiae* having a single or double defect in the expression of enzymes that catalyze the conversion of squalene to ergosterol that is transformed with a recombinant DNA molecule comprising as described before.

The present invention still further provides for recombinant DNA molecules used to transform mutant yeasts such that the transformed mutant yeast overaccumulates squalene and specific sterols. Preferred recombinant DNA molecules are plasmids pARC304S, pARC300S, pARC300T, pARC300D, pARC306E, pSOC106ARC and pSOC725ARC.

The present invention provides several benefits and advantages.

One advantage of the present invention is the provision of methods known to result in the predictable accumulation of specific sterols.

Another advantage of the present invention is the ability to accumulate specific sterols to levels markedly greater than levels found in non-transformed yeast.

Still further benefits and advantages will be apparent to the skilled worker from the description that follows.

Brief Descriptions of the Drawings

Figure 1 is a schematic diagram illustrating the various transformation steps involved in the metabolic conversion of zymosterol to ergosterol as shown and discussed in Bard et al., *Lipids*, 12(8):645 (1977). The letters (a-e) indicate the five enzymes responsible for catalyzing the individual transformation steps. Numerals alone or with the letter "C" and an enzymic name indicate the position of the enzymes' activities and the activity of each enzyme.

Figure 2, shown as twelve panels designated Figure 2-1 through 2-12, is the nucleotide base sequence (SEQ ID NO:1) and derived amino acid residue sequence (SEQ ID NO:2) for *S. cerevisiae* HMG-CoA reductase 1 published by Basson et al., *Mol. Cell Biol.* 8(9):3797-3808 (1988). Nucleotides are numbered (left-hand side) in the 5' to 3' direction. Position 1 corresponds to the first nucleotide of the ATG triplet coding for the initiator methionine. The predicted amino acid sequence is shown below the nucleotide sequence. The amino acid residues are numbered (right-hand side) beginning with the initiator methionine.

Figure 3 is a schematic diagram showing the physical structure and genetic organization of plasmid pSOC725ARC. Plasmid pSOC725ARC was constructed to place a coding sequence for a truncated HMG-CoA reductase gene under control of a GAL 1-10 promoter. This plasmid also contains the TRP-1 gene and the yeast 2 micron origin of replication. Certain restriction sites indicated by lines linked to the arcs and abbreviation for their respective restriction endonuclease enzymes are indicated.

Figure 4 is a schematic diagram showing the physical structure and genetic organization of plasmid pSOC106ARC. Plasmid pSOC106ARC was constructed to place a coding sequence for an intact HMG-CoA reductase gene under the control of a GAL 1-10 promoter. Plasmid pSOC106ARC also contains the TRP-1 gene and the yeast 2micron origin of replication. Certain restriction sites are indicated as in Figure 3.

Figure 5 is a schematic diagram showing the physical structure and genetic organization of plasmid pARC306E. Plasmid pARC306E was constructed to place a coding sequence for a truncated HMG-CoA reductase gene under control of a GAL-1 promoter. Plasmid pARC306E also contains the TRP-1 gene. Certain restriction sites are indicated as in Figure 3.

Figure 6 is schematic diagram showing the physical structure and genetic organization of plasmid pARC300D. Plasmid pARC300D was constructed to place a coding sequence for a truncated HMG-CoA reductase gene under the control of a PGK promoter. Plasmid pARc300D also contains the TRP-1 gene. Certain restriction sites are indicated as in Figure 3.

Figure 7 is a schematic diagram showing the physical structure and genetic organization of plasmid pARC300S. Plasmid pARC300S was constructed to place a coding sequence for a truncated HMG-coA reductase gene under control of a PGK promoter. Plasmid pARC300S also contains a URA 3 selectable marker. Certain restriction sites are indicated as in Figure 3.

Figure 8 is a schematic diagram showing the physical structure and genetic organization of plasmid pARC300T. Plasmid pARC300T was constructed to place a coding sequence for a truncated HMG-coA reduc-

tase gene under control of a PGK promoter. Plasmid pARC300T also contains a URA3 selectable marker. Certain restriction sites are indicated as in Figure 3.

Figure 9 is a schematic diagram showing the physical structure and genetic organization of plasmid pARC304S. Plasmid pARC304S was constructed to place a coding sequence of a truncated HMG-CoA reductase gene under the control of an ADH promoter. Plasmid pARC304S also contains a URA3 selectable marker. Certain restriction sites are indicated as in Figure 3.

Detailed Description of the Invention

10 I. Definitions

The following words and phrases have the meanings set forth below.

Expression: The combination of intracellular processes, including transcription and translation, undergone by a structural gene to produce a polypeptide.

Expression vector: A DNA sequence that forms control elements that regulate expression of structural genes when operatively linked to those genes.

Operatively linked: A structural gene is covalently bonded in correct reading frame to another DNA (or RNA as appropriate) segment, such as to an expression vector so that the structural gene is under the control of the expression vector.

Promoter: A recognition site on a DNA sequence or group of DNA sequences that provide an expression control element for a structural gene and to which RNA polymerase specifically binds and initiates RNA synthesis (transcription) of that gene.

Recombinant DNA molecule: A hybrid DNA sequence comprising at least two nucleotide sequences not normally found together in nature.

Structural gene: A DNA sequence that is expressed as a polypeptide, i.e., an amino acid residue sequence.

Vector: A DNA molecule capable of replication in a cell and/or to which another DNA segment can be operatively linked so as to bring about replication of the attached segment. Alternatively, a vector can be a non-replicating vector that is integrated into the chromosome of the transformed cell. A plasmid is an exemplary vector.

II. The Invention

The present invention relates to compositions and methods for increasing the accumulation of squalene and specific sterols in yeast cultures as well as to the yeast that exhibit increased squalene and sterol accumulation relative to a non-transformed yeast. Preferred yeasts are yeasts of the Saccharomyces or Candida genus. A more preferred yeast is Saccharomyces cerevisiae (S. cerevisiae).

A yeast contemplated by this invention is transformed with an added structural gene that encodes a polypeptide having HMG-CoA reductase activity, that encoded polypeptide being expressed in the transformed yeast. Preferred non-transformed yeasts are mutant species having a single or double defect in the expression of enzymes involved in converting zymosterol to ergosterol (sterol biosynthetic pathway enzymes). The non-transformed and transformed yeasts compared are of the same species, such as S. cerevisiae.

Sterol production in a yeast culture of the present invention is increased by increasing the cellular activity of the enzyme HMG-CoA reductase, which enzyme catalyzes the conversion of 3-hydroxy-3-methylglutaryl Coenzyme A (HMG-CoA) to mevalonate. As used herein, "cellular activity" means the total catalytic activity of HMG-CoA reductase in a yeast cell.

Cellular HMG-CoA reductase activity is increased by increasing the expression level of a structural gene encoding a polypeptide having HMG-CoA reductase catalytic activity. Expression of that encoded structural gene enhances the cellular activity of that enzyme. The expression level is increased by methods well known in the art. For example, expression of a structural gene is increased by deregulating the promoter, which controls expression of such a structural gene. The promoter that regulates expression of the HMG-CoA reductase gene in a normal, wild-type yeast can be identified and excised from the genome. A new promoter, which allows for overexpression of the HMG-CoA reductase gene, is then inserted according to standard transformation techniques. A preferred means of increasing the expression level of a structural gene encoding a polypeptide having HMG-CoA reductase catalytic activity is to increase the copy number of a structural gene encoding such a polypeptide.

The copy number is increased by transforming a yeast cell with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes a polypeptide having HMG-CoA reduc-

tase activity, and a promoter suitable for driving the expression of said polypeptide in said yeast. Such a polypeptide is catalytically active, and is preferably a truncated HMG-CoA reductase protein.

Thus, a transformed yeast cell has one or more additional genes that encode a polypeptide having HMG-CoA reductase activity relative to a non-transformed yeast of the same species. As such, a transformed yeast can be distinguished from a non-transformed yeast by standard technology such as agarose separation of DNA fragments or mRNAs followed by transfer and appropriate blotting with DNA or RNA or by use of polymerase chain reaction technology, as are well known. Relative HMG-CoA reductase activity of the transformed and non-transformed yeasts can also be compared, with a relative increase in HMG-CoA reductase activity in transformed yeasts being indicative of transformation.

The accumulation of squalene and specific sterols can also be used to distinguish between non-transformed and transformed yeasts.

A. Structural Genes

The present invention contemplates transforming a yeast with a structural gene that encodes a polypeptide having HMG-CoA reductase activity. The HMG-CoA reductase enzymes of both animal and yeast cells comprise three distinct amino acid residue sequence regions, which regions are designated the catalytic region, the membrane binding region and the linker region.

The catalytic region contains the active site of the HMG-CoA reductase enzyme and comprises about forty percent of the total, localized on the COOH-terminal portion of intact HMG-CoA reductase enzyme. The membrane binding region contains hydrophobic amino acid residues and comprises about fifty percent of the total, localized on the NH₂-terminal portion of intact HMG-CoA reductase enzyme. The linker region connects the catalytic and membrane binding regions, and constitutes the remaining about ten percent of the intact enzyme.

As discussed in greater detail below, only the catalytic region of HMG-CoA reductase is needed herein. Thus, a structural gene that encodes a polypeptide corresponding to that catalytic region is the minimal gene required for transforming yeasts. However, larger polypeptide enzymes and their structural genes are preferred. Thus, the present invention contemplates use of truncated structural genes that encode the active catalytic region, or the catalytic region plus at least a portion of the linker region that is free from the membrane binding region of HMG-CoA reductase.

A structural gene encoding a polypeptide having HMG-CoA reductase activity can be obtained or constructed from a variety of sources and by a variety of methodologies, [See, e.g., Carlson et al., *Cell*, **28**:145 (1982); Rine et al., *Proc. Nat. Acad. Sci. U.S.A.*, **80**:6750 (1983)]. Exemplary of such structural genes are the mammalian and yeast genes encoding HMG-CoA reductase.

The mammalian genome contains a single gene encoding HMG-CoA reductase. The nucleotide base sequence of the hamster and human gene for HMG-CoA reductase have been described. A composite nucleotide sequence of cDNA corresponding to the mRNA, as well as the derived amino acid residue sequence, for hamster HMG-CoA reductase is found in Chin et al., *Nature*, **308**:613 (1984) and SEQ ID NO:3. The composite nucleotide sequence in that paper, comprising about 4606 base pairs, includes the nucleotide sequence encoding the intact hamster HMG-CoA reductase enzyme.

Intact hamster HMG-CoA reductase comprises about 887 amino acid residues, shown in SEQ ID NO:4.

A preferred structural gene is one that encodes a polypeptide corresponding to only the catalytic region of the enzyme. Two catalytically active segments of hamster HMG-CoA reductase have been defined, [Liscum et al., *J. Biol. Chem.*, **260**(1):522 (1985)]. One catalytic region has an apparent size of about 63 kDa and comprises amino acid residues from about position 373 to about position 887 of SEQ ID NO:4. A second catalytic region has an apparent size of about 53 kDa and comprises amino acid residues from about position 460 to about position 887 of SEQ ID NO:4. The about 63 kDa catalytically active segment is encoded by base pairs from about nucleotide position 1282 to about nucleotide position 2824 of the sequence in SEQ ID NO:3. The about 53 kDa catalytically active segment is encoded by base pairs from about nucleotide position 1543 to about nucleotide position 2824 of the sequence in SEQ ID NO:3.

In a preferred embodiment, the utilized structural gene encodes the catalytic region and at least a portion of the linker region of HMG-CoA reductase. The linker region of hamster HMG-CoA reductase comprises amino acid residues from about position 340 to about position 373 or from about position 340 to about position 460, depending upon how the catalytic region is defined. These linker regions are encoded by base pairs from about nucleotide position 1183 to about nucleotide position 1282 or from about position 1183 to about position 1543 respectively of the sequence in SEQ ID NO:3. The structural gene encoding the linker region is operatively linked to the structural gene encoding the catalytic region.

In one particularly preferred embodiment, a structural gene encoding a catalytically active, truncated HMG-CoA reductase enzyme can optionally contain base pairs encoding a small portion of the membrane region of

the enzyme. A truncated hamster HMG-CoA reductase gene, designated HMGR-Δ227, comprising nucleotides 164-190 and 1187-2824 of the sequence in SEQ ID NO:3, which encodes amino acid residues 1-8 (from the membrane binding region) and 342-887 has been used to transform cells lacking HMG-CoA reductase [Gil et al., *Cell*, 41:249 (1985)].

6 A structural gene encoding a polypeptide comprising a catalytically active, truncated or intact HMG-CoA reductase enzyme from other organisms such as yeast can also be used in accordance with the present invention.

Yeast cells contain two genes encoding HMG-CoA reductase. The two yeast genes, designated HMG1 and HMG2, encode two distinct forms of HMG-CoA reductase, designated HMG-CoA reductase 1 and HMG-CoA reductase 2. The nucleotide base sequence of HMG1 (SEQ ID NO:1) as well as the amino acid residue sequence of HMG-CoA reductase 1 (SEQ ID NO:2) are presented in Figure 2, reprinted from Basson et al., *Mol. Cell Biol.*, 8(9):3797 (1988).

The entire HMG1 gene comprises about 3360 base pairs. Intact HMG-CoA reductase 1 comprises an amino acid sequence of about 1054 amino acid residues.

15 The entire HMG2 gene comprises about 3348 base pairs shown in SEQ ID NO:5. Intact HMG-CoA reductase 2 comprises about 1045 amino acid residues shown in SEQ ID NO:6 (Basson et al., above).

By analogy to the truncated hamster structural gene, structural genes encoding polypeptides comprising catalytically active, truncated HMG-CoA reductase enzymes from yeast can also be used in accordance with the present invention.

20 The catalytic region of HMG-CoA reductase 1 comprises amino acid residues from about residue 618 to about residue 1054; i.e., the COOH-terminus. A structural gene that encodes the catalytic region comprises base pairs from about nucleotide position 1974 to about position 3282 of Figure 2 and SEQ ID NO:1.

The linker region of HMG-CoA reductase 1 comprises an amino acid sequence from about residue 525 to about residue 617. A structural gene that encodes the linker region comprises nucleotides from about position 25 1695 to about position 1974 of Figure 2. A structural gene encoding a polypeptide comprising the catalytic region and at least a portion of the linker region of yeast HMG-CoA reductase 1 preferably comprises the structural gene encoding the linker region of the enzyme operatively linked to the structural gene encoding the catalytic region of the enzyme.

Also by analogy to the truncated hamster gene, a truncated HMG1 gene can optionally contain nucleotide 30 base pair sequences encoding a small portion of the membrane binding region of the enzyme. Such a structural gene preferably comprises base pairs from about nucleotide position 121 to about position 146 and from about position 1695 to about position 3282 of Figure 2 and SEQ ID NO:1.

A construct similar to those above from an analogous portion of yeast HMG-CoA reductase 2 can also be utilized.

35 It will be apparent to those of skill in the art that the nucleic acid sequences set forth herein, either explicitly, as in the case of the sequences set forth above, or implicitly with respect to nucleic acid sequences generally known and not presented herein, can be modified due to the built-in redundancy of the genetic code and non-critical areas of the polypeptide that are subject to modification and alteration. In this regard, the present invention contemplates allelic variants of structural genes encoding a polypeptide having HMG-CoA reductase 40 activity.

The previously described DNA segments are noted as having a minimal length, as well as total overall lengths. That minimal length defines the length of a DNA segment having a sequence that encodes a particular polypeptide having HMG-CoA reductase activity. As is well known in the art, so long as the required DNA sequence is present and in proper reading frame, (including start and stop signals), additional base pairs can be 45 present at either end of the segment and that segment can still be utilized to express the protein. This, of course, presumes the absence in the segment of an operatively linked DNA sequence that represses expression, expresses a further product that consumes the enzyme desired to be expressed, expresses a product other than the desired enzyme or otherwise interferes with the structural gene of the DNA segment.

Thus, so long as the DNA segment is free of such interfering DNA sequences, the maximum size of a recombinant DNA molecule, particularly an expression vector, is governed mostly by convenience and the vector size 50 that can be accommodated by a host cell, once all of the minimal DNA sequences required for replication and expression, when desired, are present. Typically, a DNA segment of the invention can be up to 15,000 base pairs in length. Minimal vector sizes are well known.

55 B. Recombinant DNA Molecules

A recombinant DNA molecule of the present invention can be produced by operatively linking a vector to a useful DNA segment to form a plasmid such as discussed herein. Particularly preferred recombinant DNA

molecules are discussed in detail in Examples 2 to 7, hereafter. A vector capable of directing the expression of a polypeptide having HMG-CoA reductase activity is referred to herein as an "expression vector".

Such expression vectors contain expression control elements including the promoter. The polypeptide coding genes are operatively linked to the expression vector to permit the promoter sequence to direct RNA polymerase binding and expression of the desired polypeptide coding gene. Useful in expressing the polypeptide coding genes are promoters that are inducible, viral, synthetic, constitutive as described by Poszakowski et al., EMBO J., 3:2719 (1989) and Odell et al., Nature, 313:810 (1985), and temporally regulated, spatially regulated, and spatiotemporally regulated as disclosed in Chau et al., Science, 244:174-181 (1989). The promoter preferably comprises a promoter sequence whose function in regulating expression of the structural gene is substantially unaffected by the amount of sterol in the cell. As used herein, the term "substantially unaffected" means that the promoter is not responsive to direct feedback control by the sterols accumulated in transformed cells.

5 A promoter is also selected for its ability to direct the transformed yeast's transcriptional activity to the structural gene encoding a polypeptide having HMG-CoA reductase activity. Structural genes can be driven by a variety of promoters in yeast.

10 Promoters utilized with the present invention are those preferably regulated by factors, which can be monitored and controlled in the internal or external environment of the transformed cell. Examples of promoters inducibly regulated by factors in the cell's external environment (extrinsic factors) are the GAL 1 promoter, the GAL 10 promoter, the GAL 1-10 promoter, the GAL 7 promoter, the metallothionein promoter, the a-factor promoter, the invertase promoter and the enolase promoter. Preferred are the well known GAL 1, the GAL 10 and the GAL 1-10 promoters.

15 Examples of promoters subject to inducible regulation by factors in the cell's internal environment (intrinsic factors) are the phosphoglycerate kinase (PGK) promoter, the triose-phosphate isomerase (TPI) promoter, the alcohol dehydrogenase (ADH) promoter and the repressible acid phosphatase promoter. Preferred are the well known PGK and the ADH promoters.

20 The choice of which expression vector and ultimately to which promoter a polypeptide coding gene is operatively linked depends directly on the functional properties desired, e.g. the location and timing of protein expression, and the host cell to be transformed. These are well known limitations inherent in the art of constructing recombinant DNA molecules. However, a vector useful in practicing the present invention is capable of directing the expression of the polypeptide coding gene included in the DNA segment to which it is operatively linked.

25 The present method contemplates a plasmid vector. The plasmid vectors of the present invention can be incorporated either within (integrated) or without (episomal) the chromosomes of the transformed cell. An episomal plasmid includes an origin of replication for yeast, the nucleic acid sequence that encodes a polypeptide having HMG-CoA reductase activity, a promoter, and a selective marker. The selective marker can include genes conveying antibiotic resistance, or permitting an auxotrophic host to metabolize a substrate that it would not otherwise be able, but for the presence of the plasmid vector. However, the use of antibiotic resistance as a selective marker requires growing organisms in an antibiotic culture media. Due to the expense of the antibiotic, organisms dependent on antibiotics are difficult to develop commercially. Generally, auxotrophic organisms are used for yeast.

30 Auxotrophic organisms can be produced by mutation and culture techniques which are well known in the art. Selective markers which can complement an auxotrophic host organism include the well known TRP 1 gene encoding phosphoribosyl anthranilic isomerase, the URA 3 gene encoding orotidine-5' phosphate decarboxylate, the LEU 2 gene encoding isopropylmalate isomerase, and the HIS 3 gene encoding histidinal dehydrogenase. A preferred selective marker for an auxotrophic host is TRP 1. Preferred episomal plasmid vectors are pSOC725ARC and pSOC106ARC.

35 Episomally replicating vectors are sometimes difficult to maintain in host organisms for long periods of time in liquid culture, especially when the selective pressure used to maintain the vector is complementation of a nutritional auxotrophy. A preferred embodiment of the present invention includes an integrating vector which requires little or no selective pressure to maintain base sequences for the polypeptide having HMG-CoA reductase activity and the promoter.

40 Integrating vectors, in accordance with the present invention, include base sequences that encode a polypeptide having HMG-CoA reductase activity, a promoter, a selective marker and sequences homologous to host chromosomal DNA that permit the base sequences to be incorporated within the chromosome via homologous recombination. The homologous region includes restriction sites that permit the plasmid to become linear. In linear form, the plasmid can recombine at homologous regions of the chromosome. Integrating vectors do not include origins of replication for the host organism.

45 Preferred integrating vectors are pARC300S, pARC300T, pARC300D, pARC306E and pARC304S. Plasmid vector pARC304S is most preferred as evidenced by its ability to generate the greatest enhancement in

sterol accumulation (see Example 15). The basic genetic characteristics of preferred plasmid vectors are summarized in Table 2, below.

TABLE 2

<u>Plasmid Vector</u>	<u>Genetic Characteristics</u>
pSOC106	TRP1-2μori-GAL 1-HMG1*
pSOC725	TRP1-2μori-GAL 10-tHMG1**
pARC306E	TRP1-GAL 1-tHMG1
pARC300D	TRP1-PGK-tHMG1
pARC300S,T	URA3-PGK-tHMG1-ura3 term
pARC304S	URA3-ADH-tHMG1-ura3 term

* HMG1 - gene encoding intact *S. cerevisiae* HMG-CoA reductase 1.

** tHMG1 - gene encoding catalytic region and a portion of the linker region of *S. cerevisiae* HMG-CoA reductase 1.

Individuals skilled in the art will readily recognize that episomal and integrating vectors are often amplified in organisms other than the intended host and require means of replication and selection in the non-host organism. Generally, the non-host organism is *Escherichia coli* due to its well-known features and characteristics.

In preferred embodiments, the vector used to express the polypeptide coding gene includes a selection marker that is effective in a yeast cell, such as the URA3 or TRP1 markers. Other suitable selection means for use in amplifying the vectors in bacteria include antibiotic markers, such as genes encoding for beta lactamase (penicillin resistance), chloramphenicol transacetylase (chloramphenicol resistance), and neomycin phosphotransferase (kanamycin and neomycin resistance).

A variety of methods has been developed to operatively link DNA to vectors via complementary cohesive termini or blunt ends. For instance, complementary homopolymer tracts can be added to the DNA segment to be inserted and to the vector DNA. The vector and DNA segment are then joined by hydrogen bonding between the complementary homopolymeric tails to form recombinant DNA molecules.

Alternatively, synthetic linkers containing one or more restriction endonuclease sites can be used to join the DNA segment to the expression vector. The synthetic linkers are attached to blunt-ended DNA segments by incubating the blunt-ended DNA segments with a large excess of synthetic linker molecules in the presence of an enzyme that is able to catalyze the ligation of blunt-ended DNA molecules, such as bacteriophage T4 DNA ligase. Thus, the products of the reaction are DNA segments carrying synthetic linker sequences at their ends. These DNA segments are then cleaved with the appropriate restriction endonuclease and ligated into an expression vector that has been cleaved with an enzyme that produces termini compatible with those of the synthetic linker. Synthetic linkers containing a variety of restriction endonuclease sites are commercially available from a number of sources including New England BioLabs, Beverly, MA.

Also contemplated by the present invention are RNA equivalents of the above described recombinant DNA molecules.

C. Transformed Yeasts and Methods of Transformation

The copy number of a gene coding for a polypeptide having HMG-CoA reductase activity is increased by transforming a desired yeast with a suitable vector that contains that structural gene. Expression of that gene in the transformed yeast enhances the activity of HMG-CoA reductase.

Yeast cells are transformed in accordance with the present invention by methods known and readily apparent to those of skill in the yeast transformation art, [See, e.g., Hinnen et al., Proc. Natl. Acad. Sci. USA, **75**:1929 (1978); Ito et al., Bact., **5**:163-168 (1983)].

5 A preferred general method of transformation is the lithium acetate procedure of Ito et al., above. Yeast cells are grown to a concentration about 2×10^7 cells/ml in a medium containing yeast extract, bactopeptone and dextrose. Cells are collected by low speed centrifugation and resuspended in a transformation medium containing lithium acetate in a Tris-EDTA buffer.

10 Cells are maintained in the transformation medium for about one hour at about 30°C. Recombinant DNA molecules of desired composition are added to the transformation medium cell suspension and the mixture is maintained at about 30°C for about one-half hour. Polyethylene glycol (M.W. 4000) is then added to the cell suspension such that the final concentration of polyethylene glycol is about 35 percent weight/volume (w/v). Cells are maintained in the polyethylene glycol-containing solution at about 30°C for about two hours and then at about 42°C for an additional five minutes. Sterile distilled water is added to the cell suspension, and the cells collected by low speed centrifugation. Further specifics are provided hereinafter.

15 Successfully transformed cells are identified by growing the transformed cells on selection medium, identifying cell characteristics indicative of transformation (i.e., increased accumulation of squalene or specific sterols), analyzing nucleic acids isolated from such transformed cells with standard techniques such as Southern blot analysis, [Holm et al., Gene, **42**:169 (1986)].

20 D. Mutated Yeasts

The yeasts utilized in accordance with the present invention are mutated yeasts having single or double defects in the expression of enzymes that catalyze the conversion of zymosterol to ergosterol. Such enzymes are referred to herein as "erg" gene products. Table 3 below lists the particular erg designations for specific enzyme expression defects.

Table 3

	<u>Enzyme Expression Defect</u>	<u>Mutant Designation</u>
30	zymosterol-24-methyltransferase	erg6
	ergosta-5,7,24(28)-trienol-22-dehydrogenase	erg5
35	episterol-5-dehydrogenase	erg3

Mutants used in accordance with the present invention can be purchased or generated from commercially available sources such as the Yeast Genetic Stock Center (Berkeley, CA.). For example, erg5 and erg5-erg6 double mutants are produced from commercially available sources.

40 Mutant yeast ATC0402mu, an erg5-erg6 double mutant, is constructed by crossing a commercially available erg6 mutant yeast, M610-12B, with a commercially available erg5 mutant, pol5αΔ22, and then crossing the resultant double mutant, ATC0403mu, with a wild-type yeast. Mutant yeast ATC0402mu and its derivative mutant yeast ATC0315rc are the most preferred mutants for transformation with the plasmid vectors of the present invention.

45 Alternatively, ATC0403 is crossed with a different wild-type, and mutants having desired genotypes are back-crossed twice with wild-type yeast to yield species ATC4124, an erg5 mutant.

Mutants are also obtained by well known methods of inducing mutations. See, e.g., Boeke et al., Mol. Gen. Genet., **197**:345-346 (1984); Sherman et al., Methods and Yeast Genetics, Cold Spring Harbor Laboratory, N.Y. (1986).

50 In a preferred embodiment, wild-type yeasts are transformed with an inducible "TY1-neo" transposon as a mutagenic agent. Plasmid pJEF1105, containing a GAL-TY1-neo expression cassette, is used as the transforming agent. Boeke et al., Science **239**:280-282 (1989). Competent transformants demonstrating both neomycin and nystatin resistance are then evaluated for sterol content.

55 Transformation of wild-type yeast with pJEF1105 yields mutant ATC6118, an erg3 mutant, and mutant ATC0501, an erg6 mutant.

Mutants having single expression defects are then crossed to generate mutants having double defects in enzyme expression. For example, the crossing of mutant ATC6118 with mutant ATC0501 yields mutant

ATC6119, an erg3-erg6 double mutant.

The genotype of exemplary mutants contemplated for use in the present invention are presented in Table 4 below. Genotype symbols are used in accordance with convention cited in Mortimer et al. *Yeast*, 5:321-403 (1989) and Broach, *The Molecular Biology of the Yeast Saccharomyces, Life Cycle and Inheritance*, Strath m, Jones and Broach, eds., Cold Spring Harbor Laboratory, pp. 653-727 (1981).

Table 4

<u>Species</u>	<u>genotype</u>
pol5aΔ22	a, erg5
M610-12β	α, ile3, erg6-5, trpl, gal2
DBY745	α, ade1, ura3-52, leu2-100, leu2-122, MEL, gal 1 gal 10
YNN281	α, trpl-Δ, his3Δ-200, ura 3-52, lys 2
ATC0403mu	a, trpl, gal, erg5, erg6
ATC0402mu	a, trpl, GAL, erg5, erg6
ATC6118	a, his3Δ-200, erg3, ura3-52, GAL
ATC4124	α, erg5, trpl, GAL
ATC4154	a, ura3-52, erg7, gal
ATC6119	α, erg3, erg6, ura3-52, GAL
ATC1500cp	a, erg5, erg6
ATC0315rc	a, ura3, erg5, erg6
ATC1551	a, erg5, erg6

E. Squalene and Sterol Accumulation in Transformed Yeast

The transformed mutant yeast species of the present invention overaccumulate squalene and specific sterols relative to non-transformed mutants of the same species. Relative to a non-transformed erg3 mutant, an erg3 mutant transformed with a plasmid vector used herein overaccumulates squalene, ergosta-8,22-dienol, ergosta-7,22-dienol, ergosta-8-enol and ergosta-7-enol.

Relative to a non-transformed erg5 mutant, an erg5 mutant transformed with a plasmid vector used herein overaccumulates squalene, zymosterol, and a mixture of ergosta-5,7,24(28)-triol and ergosta-5,7 dienol.

Similar results are seen when mutants having double defects in enzymes of the sterol synthetic pathway are transformed. Relative to a non-transformed erg3-erg6 mutant, an erg3-erg6 mutant transformed with a useful plasmid vector overaccumulates squalene, zymosterol and cholesta-7,24-dienol.

Relative to a non-transformed erg5-erg6 mutant, an erg5-erg6 double mutant transformed with the plasmid vector useful herein overaccumulates squalene, zymosterol, cholesta-5,7,24-trienol and cholesta-7,24-dienol.

F. HMG-CoA Reductase Activity In Transformed Yeasts

The expression of a structural gene encoding a polypeptide having HMG-CoA reductase activity in the transformed yeast of the present invention enhances the cellular activity of said HMG-CoA reductase. As a result of transformation, the copy number of an added gene encoding a polypeptide having HMG-CoA reductase activity is increased from 1 to about 2 to about 10.

Cellular activity of HMG-CoA reductase in such transformed cells is almost linearly proportional to the increase in copy number through a copy number of about 6 and then falls slightly when a copy number of 9 is reached. Thus, when the copy number is increased to about 2, HMG-CoA reductase activity is elevated to a level about 1.4 times the activity observed in non-transformed yeast. A further increase in the copy number to a level of about 6 is accompanied by a further increase in HMG-CoA reductase activity to a level about 2.6 times that found in non-transformed yeast. Increases in the copy number beyond about 6 to about 9 are not accompanied by further increases in HMG-CoA reductase activity. A transformed yeast having a copy number

of about 9 has a level of HMG-CoA reductase activity about equal to about twice that seen in non-transformed yeast.

G. Harvesting of Sterols

5

If desired, transformed yeasts are harvested to recover the sterol product. Most of the sterol in our genetically transformed yeast of this invention occurs in the form of fatty acid esters. To obtain free sterols, it is therefore necessary to saponify the "yeast pulp" in base, e.g., as described in the Examples below (2:1 EtOH/H₂O containing 20 percent w/v KOH).

10

In a preferred embodiment, harvesting comprises:

- (i) homogenizing sterol-containing transformed yeasts to produce a pulp; and
- (ii) extracting the sterol(s) from the pulp with an appropriate basic solvent such as an organic solvent or by supercritical extraction followed by base saponification in an appropriate solvent [Favati et al., *J. Food Sci.*, 53:1532 (1988) and the citations therein] to produce a sterol-containing liquid solution or suspension; and

15

- (iii) isolating the sterol(s) from the solution or suspension.

20

Transformed yeasts are homogenized to produce a pulp using methods well known to one skilled in the art. This homogenization can be done manually, by a machine, or by a chemical means. The pulp consists of a mixture of the sterol of interest, residual amounts of precursors, cellular particles and cytosol contents, which is subjected to extraction procedures.

25

Sterol(s) can be extracted from the pulp produced above to form a sterol-containing solution or suspension. Such extraction processes are common and well known to one skilled in this art. For example, the extracting step can consist of soaking or immersing the pulp in a suitable solvent. This suitable solvent is capable of dissolving or suspending the sterol present in the pulp to produce a sterol-containing solution or suspension. Solvents useful for such an extraction process are well known to those skilled in the art and include several organic solvents and combinations thereof such as methanol, ethanol, isopropanol, acetone, acetonitrile, tetrahydrofuran (THF), hexane, and chloroform as well as water-organic solvent mixtures. A vegetable oil such as peanut, corn, soybean and similar oils can also be used for this extraction.

30

Yeast transformed with a structural gene for an active, truncated HMG-CoA reductase enzyme are grown under suitable culture conditions for a period of time sufficient for sterols to be synthesized. The sterol-containing yeast cells are then lysed chemically or mechanically, and the sterol is extracted from the lysed cells using a liquid organic solvent, as described before, to form a sterol-containing liquid solution or suspension. The sterol is thereafter isolated from the liquid solution or suspension by usual means such as chromatography.

35

The sterol is isolated from the solution or suspension produced above using methods that are well known to those skilled in the art of sterol isolation. These methods include, but are not limited to, purification procedures based on solubility in various liquid media, chromatographic techniques such as column chromatography and the like.

Best Mode For Carrying Out The Invention

40

The following examples illustrate the best mode of carrying out the invention and are not to be construed as limiting of the specification and claims in any way.

EXAMPLE 1: Transformation of *S. Cerevisiae*

45

Yeast of the species *S. cerevisiae* were transformed in accordance with a lithium acetate procedure, [Ito et al., *J. Bacteriol.*, 153:163-168 (1983)]. Yeast cells were grown in about 50 ml of YEPD medium (yeast extract 1 percent w/v, bactopeptone, 2 percent w/v; and dextrose, 2 percent w/v) overnight at about 30°C. When the concentration of cells was about 2 x 10⁷ cells/ml, the cells were collected by low speed centrifugation. Cells appearing in the pellet of the centrifugation were suspended in about 50 mls of TE buffer (10 mM Tris-Cl, 1 mM EDTA) and resuspended by centrifugation. The pellet from this second centrifugation was resuspended in about 1.0 ml of TE buffer. To 0.5 ml of this cell suspension were added 0.5 ml of 0.2 M lithium acetate (LIOAc), and the suspension was maintained at about 30°C for one hour with constant shaking.

50

Recombinant DNA (about 10 µg in up to 15 µl of TE buffer) was added to 100 µl of the TE-LIOAc cell suspension and the admixture maintained at about 30°C for one-half hour without shaking. The DNA-containing cell suspension was then well mixed with polyethylene glycol (44 percent w/v) such that the final concentration of polyethylene glycol (PEG) was about 35 percent (w/v).

The cells were maintained in this PEG solution at about 30°C for about two hours and then at about 42°C

for about five minutes. About 10 ml of sterile, distilled water was added to each suspension and the cells were collected by low speed centrifugation. This procedure was repeated, and the collected cells were dispersed in about 1.0 ml of distilled water. Approximately 100 to 200 µl of this suspension were then spread-plated on selective medium.

5 Transformation of cells was confirmed by growth on selection medium, identification of cell characteristics indicative of transformation (i.e., increased levels of selected sterols or squalene), and Southern blot analysis of nucleic acid isolated from such transformed cells [Holm et al., *Gene*, 42:169-173 (1986)].

EXAMPLE 2: Construction of Episomal Plasmid pSOC725ARC

10 Plasmid pSOC725ARC (See Figure 3) was constructed to place a coding sequence for a truncated HMG1 gene under control of the GAL 1 portion of a GAL 1-10 promoter. Plasmid pSOC725ARC also contains the TRP 1 gene and the yeast 2 micron origin of replication (IR1). This plasmid was prepared from intermediate plasmids as follows.

15 The TRP 1-ARS gene of S. cerevisiae was removed from plasmid YRP12 [Stinchcomb et al., *Nature*, 282:39 (1979)] by digestion with Eco RI. The 1445 base pair DNA fragment containing the TRP 1-ARS gene was purified on an agarose gel and ligated into plasmid pUC8 (Viera et al., *Gene*, (1982)), which had been digested with Eco RI to form plasmid pSOC742.

20 A yeast episomal replication origin, obtained from purified S. cerevisiae two-micron plasmid DNA, was digested with Eco RI and then treated with the Klenow fragment of E. coli DNA polymerase 1 to yield an about 2240 base pair fragment containing the two-micron origin of DNA replication. The about 2240 base pair fragment was purified by agarose gel electrophoresis and ligated into plasmid pUC8, which had been digested with Sma I to form plasmid pSOC743.

25 Plasmid pSOC742 was cleaved with Bam HI and Bgl II to yield an 857 base pair, TRP 1-containing gene fragment, which was inserted into pSOC743 that had been cut with Bam HI to form plasmid pSOC744.

The MEL 1 gene was removed from plasmid pMP550 [Summer-Smith et al., *Gene*, 36:333-340 (1985)] with restriction endonucleases Eco RI and Bam HI, and the about 2858 base pair restriction fragment containing MEL 1 was purified on an agarose gel. The purified fragment was then ligated into plasmid pUC8 which had been digested with Eco RI and Bam HI to form plasmid pSOC741.

30 The final stage of assembly of pSOC740 was achieved by purifying an about 3101 base pair, Eco RI restriction fragment of pSOC744 that contained the TRP 1 and two-micron origin, and ligating it into Eco RI-cleaved plasmid pSOC741 to form plasmid pSOC740.

The GAL 1-10 promoter was excised from pBM258, [Johnston et al., *Proc. Natl. Acad. Sci. USA*, 79:6971-6975 (1982)] as a 685 base pair Bam HI-Eco RI restriction fragment, and ligated into pUC18, which had been digested with Bam HI and Eco RI to form plasmid pSOC711.

35 Plasmid pSOC740 was digested with Eco RI and the resulting 3101 base pair fragment, containing the two-micron origin of replication and the TRP 1 gene, was isolated and ligated into the Eco RI digested plasmid pSOC711 to produce plasmid pSOC712, in which the TRP 1 gene is proximal to the GAL 1-10 promoter.

A Pst I restriction site spanning the coding sequence for amino acid residues 529-530 of HMG-CoA reductase 1 was chosen as the point at which to introduce both a new Bam HI restriction site and a new initiator methionine codon. A 1706 base pair Pst I-Eco RI restriction fragment, containing the coding sequence for the COOH-terminal half of HMG-CoA reductase 1, was purified from a digest of pJR59, [Basson et al., *Proc. Natl. Acad. Sci. USA*, 83:5563-5567 (1986)]. This purified pJR59 fragment and a synthetic oligonucleotide:

45 d5' -GATCCGTCGACGCATGCCCTGCA-3' (SEQ ID NO:7)
d3' -GCAGCTGCGTACGG-5' (SEQ ID NO:8)

50 were ligated with pUC18 [Yanisch-Perron et al., *Gene*, 33:103-119 (1985)], which had been cleaved with Bam HI and Eco RI.

The resulting plasmid, pSOC937, contained a Bam HI restriction site 12 base pairs upstream of the truncated HMG-CoA reductase coding sequence initiator methionine. The polypeptide formed from initiation at that point had initial methionine and proline residues followed by amino acid residues 530 through 1054 of the natural HMG-CoA reductase 1.

55 The Eco RI restriction site, which is at the 3' end of the gene, is located 135 base pairs past the end of the coding sequence for the truncated HMG-CoA reductase protein. The truncated gene for HMG-CoA reductase was placed into plasmid pSOC712 by converting the Eco RI site at the 3' end of the truncated reductase gene to a Bam HI site (Klenow polymerase filled, ligated to an oligonucleotide, d5'-CGGATCC-, specifying the Bam

HI restriction site) and cleaving the preparation with endonuclease Bam HI. A purified, resulting 1728 base pair Bam HI ended restriction fragment from pSOC937 was ligated into the Bam HI-digested pSOC712 to produce plasmid pSOC725ARC, whose schematic restriction map is shown in Figure 3.

5 EXAMPLE 3: Construction of Episomal Plasmid pSOC108ARC

Plasmid pSOC106ARC (See Figure 4) was constructed to place a coding sequence for intact HMG1 under the control of the GAL 1 portion of a GAL 1-10 promoter.

10 A 610 base pair Bgl II fragment from pJR59 (about positions 9026-9836), containing the DNA surrounding the beginning of the HMG-CoA reductase coding sequence, was isolated and further restricted with Dde I to provide a DNA fragment (about positions 9151-9836) starting 68 base pairs upstream of the first codon of the HMG-CoA reductase coding sequence.

The Dde I and Bgl II fragments were treated with the Klenow fragment of DNA polymerase to render the ends "blunt." The fragments were then ligated to oligonucleotide linkers, d5'-CCGGATCCGG-3 (SEQ ID NO:9), specifying a Bam HI cleavage site (BRL linkers). The ligated fragments were digested with Bam HI to produce ligatable Bam HI restriction ends, and the resulting 499 base pair fragment containing the start of the HMG-CoA reductase coding sequence was ligated into Bam HI digested pBR322 to form plasmid pSOC104.

The remainder of the HMG-CoA reductase coding sequence was reconstructed downstream of the new 5' Bam HI site by ligating a 1477 base pair Xba I-Sac I DNA fragment of pJR59, which specifies the 5' half of the HMG-CoA reductase coding sequence, and a 2101 base pair Sac I-Sal I fragment of pJR59, which specifies the 3' half of the HMG-CoA reductase coding sequence, into pSOC104 digested with Xba I and Sal I to form plasmid pSOC105 containing a 3903 base pair Bam HI-Sal I restriction fragment having the entire coding sequence for HMG-CoA reductase. This 3903 base pair fragment was ligated into Bam HI-Sal I-restricted pSOC712 (See Example 2) to form plasmid pSOC106ARC.

EXAMPLE 4: Construction of Integrating Plasmid pARC306E

Plasmid pARC306E (See Figure 5) was constructed to place a coding sequence for truncated HMGI under control of the GAL 1 portion of a GAL 1-10 promoter.

30 Plasmid pARC306E contains the *S. cerevisiae* TRP 1 gene and a GAL 1 promoter-driven, truncated HMG-
CoA reductase gene housed on an *E. coli* replicon, which specifies ampicillin resistance. There are no *S. cere-*
visiae replicators on plasmid pARC306E. Unique restriction sites within both the TRP 1 gene (Eco RV, position
865) and the truncated HMG-CoA reductase gene (Cla I, position 4280) serve as sites for the generation of
linear plasmids with DNA homologous to *S. cerevisiae* chromosomal DNA on both sides of the restriction site.
35 Thus, plasmid pARC306E can be incorporated into the chromosome at either site via homologous recombi-
nation.

The multiple restriction recognition site of plasmid pUC8, located between the Eco RI and Hind III sites, was replaced by the oligonucleotide:

40 d5'-AGCTTTCCGGAGCTGAGATCTAGATATCGATG (SEQ ID NO:10)
3'-AGCGCTCGAGCTCTAGATCTATAGCTACTTAA-5'
(SEQ ID NO:11)

45 to create plasmid pUC8NL, which has a single restriction site for the nuclease enzyme *Cla* I.

Plasmid pSOC712 (See Example 2) was digested with Eco RI and the fragments treated with nuclease S1 and bacteriophage T4 DNA polymerase plus deoxynucleotides to remove the overhanging 5' Eco RI restriction ends. These ends were ligated to the oligonucleotide:

d5'-CATCGATG-3'
d3'-GTAGCTAC-5'

and the fragments treated with Cia I nuclease to produce Cia I restriction ends.

The resulting 3108 base pair Cla I-Cla I fragment, containing the yeast TRP 1 gene and the two-micron replicator, was purified by gel electrophoresis and ligated into pUC8NL, which had been cleaved with Cla I, to create plasmid pARC300A.

55 A 2031 base pair fragment containing the two-micron replication origin was removed from pARC300A by treatment with nuclease Pst I. The resulting modified plasmid pARC300A was treated with nucleas S1 and bacteriophage T4 DNA polymerase plus deoxynucleotides to remove the Pst I restriction overhangs and with calf intestinal alkaline phosphatase to disallow reclosure of the plasmid. The modified pARC300A plasmid was

coligated with the oligonucleotide:

d5'-CATCGATG-3'
d3'-GTAGCCTC-5'

to introduce a Cla I site just downstream (to the 3' end) of the TRP 1 gene to form a plasmid, and then closed 5 to form pARC306B. The TRP 1 gene was separate from yeast replicators, and bounded by Cla I restriction sites.

Plasmid pARC306B was digested with Cla I, purified by polyacrylamide gel electrophoresis and the Cla I-Cla I restriction fragment was introduced into plasmid pUC8, which had been cleaved with nuclease Acc I, to form plasmid pARC306C.

As the integration of exogenous DNA into yeast chromosomes is best carried out using homologous recombination, a dispensable fragment of yeast DNA was desired. This DNA would be used to drive homologous recombination if for some reason, recombination at the TRP 1 or HMG-CoA reductase gene were not utilizable. The DNA chosen for this purpose was the HIS3 gene.

An 1800 pair Bam HI-Bam HI restriction fragment was removed from plasmid YEP6 [Struhl et al., Proc. Natl. Acad. Sci. USA, 76:1035 (1979)] and introduced into plasmid pARC306C, which had been cleaved with Bam HI, to create plasmid pARC308D. Plasmid pSOC725 (See Example 2) was digested with Eco RI to yield 15 a GAL 1-10 promoter linked to a truncated HMG-CoA reductase gene, which was then inserted into Eco RI-digested plasmid pARC306D, to form plasmid pARC306E.

EXAMPLE 5: Construction of Integrating Plasmid PARC300D

20 Plasmid pARC300D (See Figure 6) was constructed to place a coding sequence for a truncated HMG1 gene under the control of a PGK promoter. This plasmid was prepared from intermediate plasmids as follows.

Plasmid pSOC611 was constructed to determine the efficacy of the mouse metallothionein promoter as a transcriptional driver for the truncated HMG-CoA reductase gene in yeast. Construction of pSOC611 began 25 with restriction of plasmid pSOC744 (See Example 2) with Eco RI endonuclease, followed by treatment with Klenow Polymerase I and deoxynucleotide triphosphates to fill in the Eco RI restriction ends. The resulting about 3101 base pair 2-micron- and TRP 1-containing fragment of pSOC744 was ligated to pUC18 which had been cleaved with Hinc II, to form plasmid pSOC517.

30 Plasmid pSOC517 was then cleaved with Kpn I and Eco RI and the mouse metallothionein promoter was inserted as a Kpn I-Eco RI restriction fragment to form plasmid pSOC518. This promoter region is composed of the Kpn I to Bgl II fragment originally in pJYMMT (e) [Hammer et al., Journal of Applied Molecular Genetics, Vol. 1:273 (1982)] as well as a short Bgl II, Eco RI DNA fragment of unknown sequence.

The truncated HMG-CoA reductase gene was added to pSOC518 in two steps. First, the truncated HMG-CoA reductase gene was removed from pSOC725 as a Bam HI restriction fragment. This fragment was then 35 ligated into M13mp7 which had been cleaved with Bam HI. The new M13 derivative formed was designated pSOC610. The truncated HMG-CoA reductase gene was removed from pSOC610 as an Eco RI fragment and inserted into Eco RI-digested plasmid pSOC518. The resulting plasmid was designated pSOC611.

40 Plasmid pUC8 was partially digested with restriction endonuclease Hae II and religated. Transformants arising from this procedure were screened to find a plasmid missing the Hae II restriction fragment containing the portion of the lac operon which was originally present in plasmid pUC8. This new plasmid was designated pSOC505ARC. Restriction sites for the endonucleases Eco RI, Hind III and Kpn I were introduced into the Nde I site of plasmid pSOC505ARC by ligation of the oligonucleotide:

45 d5'-TATCGAATTCAAGCTTGGTACCGA-3' (SEQ ID NO:12)
3'-AGCTTAAGTTCGAACCATGGCTAT-5' (SEQ ID NO:13)

Into Nde I-digested pSOC505ARC to form plasmid pARC303A.

50 To form the new multi-cloning site, the normal multi-cloning site present in M13mp18 was altered by ligating the oligonucleotide:

d5'-GATCCAGCTGTGTAC-3' (SEQ ID NO:14)
d3'-GTCGACA-5'

55 Into Bam HI-Kpn I digested M13mp18. This resulted in an altered M13 virus, designated pARC303B. This construct lacked both the Kpn I and Sma I sites normally found in the M13mp18 multi-cloning site. The new multi-cloning site was removed as an Eco RI, Hind III restriction fragment from pARC303B, and was ligated into

Eco RI, Hind III restricted plasmid pARC303A to form plasmid pARC303C.

In addition to a variation in the normal array of sites included in the multi-cloning site, another smaller multi-cloning site was introduced into the vector, at a point some distance away from the first multi-cloning site to allow for independent manipulation of yeast auxotrophic complementation markers and other features which did not have to be proximal to the promoters and coding sequences which would be inserted in the large multi-cloning site. The new array of restriction sites was introduced by ligation of the oligonucleotide:

d5' -CCCGGGATCGATCACGT-3' (SEQ ID NO:15)

10 d3' -TGCAGGGCCCTAGCTAG-5' (SEQ ID NO:16)

into pARC303C cleaved with endonuclease Aat II to form plasmid pARC300E, which contained the series of cloning sites, Aat II, Sma I, and Cla I at the former Aat II site.

The yeast TRP 1 gene was isolated as an 820 base pair fragment from pARC306B (See Example 4) with the restriction endonuclease Cla I. The 820 base pair Cla I-Cla I fragment was purified by agarose gel electrophoresis and ligated into plasmid pARC300E, which had been digested with Cla I, to create plasmid pARC300B.

Plasmid pSOC811 was digested with Bam HI and Ssp I to yield a 1667 base pair coding sequence for the truncated HMG-CoA reductase gene which was purified by agarose gel purification. The 1667 base pair fragment was ligated to Bam HI, Hinc II restricted plasmid pARC300B to generate plasmid pARC300C.

A source of an alternate promoter to the GAL 1-10 promoter which has been used to drive transcription of the truncated HMG-CoA reductase gene was desired. Use of the GAL 1-10 promoter requires that the yeast be cultured on galactose, an expensive substrate. In order to achieve high levels of transcription through the truncated HMG-CoA reductase gene during culture, growth in the presence of the much less expensive substrate, glucose, the promoter from the S. cerevisiae phosphoglycerate kinase (PGK) gene was isolated. The sequence of the gene is available from the literature, [Hitzeman, et al., Nucl. Acid Res., 10:7791-7808 (1982)].

From the known sequence, an oligonucleotide probe sufficiently complementary to the gene to be used as a hybridization probe was synthesized:

30 d5' -ATAAAGACATTGTTTTAGATCTGTTGTAA-3' (SEQ ID NO:17)

This probe was labelled by T₄ polynucleotide kinase treatment in the presence of ³²P-ATP, and used to screen a library of bacteriophage λ subclones of the yeast genome, supplied by Maynard Olson (Washington University School of Medicine, Department of Genetics, St. Louis, Mo.). The gene was removed from this clone as an Eco RI-Hind III fragment, and subcloned into M13mp18, forming a new phage mARC127.

To make the PGK promoter useful, the restriction site at the 5' end of the promoter was changed to an Eco RI restriction site, and a Bgl II restriction site was introduced into the DNA fragment to the 3' side of the transcriptional start site. The Bgl II restriction site was introduced by using the oligonucleotide:

40 d5' -ATAAAGACATTGTTTTAGATCTGTTGTAA-3' (SEQ ID NO:17),

to mutagenize mARC127 according to the procedure of Kunkel et al., Proc. Natl. Acad. Sci. USA, 82:4778 (1985). This resulted in the M13 phage designated mARC128.

The Hind III site beyond the 5' end of the promoter region was converted to an Eco RI site by cutting mARC128 with nuclease Hind III, treating with the Klenow fragment of DNA polymerase and the four deoxynucleotide triphosphates, followed by ligation in the presence of the oligonucleotide:

d5'-GGAATTCC-3',

which specifies an Eco RI site. The resulting M13 derivative was designated pARC306L.

Plasmid pARC306L was digested with Eco RI and Bgl II and a 1500 base pair fragment containing the PGK promoter, was purified by agarose gel electrophoresis and ligated into pARC300C, which had been restricted with Eco RI and Bam HI, to produce plasmid pARC300D.

EXAMPLE 6: Construction of Integrating Plasmids pARC300S and pARC300T

55 Plasmids pARC300S (See Figure 7) and pARC300T (See Figure 8) were constructed to incorporate a URA3 selectable marker into an integrating vector, in which a coding sequence for a truncated HMG1 gene was under the control of a PGK promoter.

The only difference between plasmid pARC300S and pARC300T is the length of the PGK promoter driving

transcription of the truncated reductase coding sequence. A unique Eco RV restriction site found within the URA 3 gene allows the plasmids to be linearized and integrated via homologous recombination into the chromosomal URA 3 gene.

5 The URA 3 gene from plasmid YEP24 (Botstein, et al., Gene, 8:17-24 (1979)) was removed as an 1127 base pair Eco RI-Sma I ended restriction fragment and ligated into plasmid pUC19, cut with Eco RI and Sma I to form a new plasmid LpARCLH550. An 1141 base pair Hind III ended restriction fragment was removed from LpARCLH550 and ligated into Hind III-cleaved pUC18 to form plasmid LpARCLH553a. An 1108 base pair Sma I-Hind III restriction fragment was removed from LpARCLH553a and inserted into Sma I-Hind III cleaved M13mp19 nucleic acid to create a new phage nucleic acid pARC308K. The unique PstI site within the URA 3 gene was eliminated by mutagenesis with the oligonucleotide:

10 d5' GATTTATCTCGTTCTGCAAAGTTTGTTC-3' (SEQ ID NO:18),

15 using the method of Kunkel, L.M.; et al., Proc. Natl. Acad. Sci. USA, 82:4778 (1985), to form plasmid pARC300Z.

Plasmid pARC300Z was cut with Hind III, the ends filled in with the Klenow fragment of DNA polymerase and deoxynucleotide triphosphates, and the modified pARC300Z ligated with oligonucleotide d5'-CCCCGGGG-3', which specified a Sma I restriction site. This new M13 derivative, which contains the URA 3 gene on a Sma I restriction fragment, was named plasmid pARC300Y.

20 Plasmid pARC304A was constructed to provide a source of a modified URA 3 transcription terminator fragment which could then be introduced at the 3' end of the coding sequence region in a yeast integrating transformation vector. The transcription terminator would function to improve mRNA stability in species transformed with integrating vectors containing coding sequences either lacking the terminator or having only weak terminator sequences. Improved mRNA stability could mean increased activity of the protein encoded by the coding sequence region. The terminator chosen was a region of the S. cerevisiae URA 3, which functions as a terminator, [Yarger et al., Molecular and Cellular Biology, 6:1095 (1986)]. The terminator sequence was constructed using 4 synthetic oligomers:

30 d5' -AGCTTCGAAGAACGAAGGAAGGAGCACAGACTTAG-3'
(SEQ ID NO:19)

35 d5' -ATTGGTATAATACGCATATTGCGGCCGCGGTAC-3'
(SEQ ID NO:20)

d5' -CGCGGCCGCAATATGCGTATATATAC-3'
(SEQ ID NO:21)

40 d5' -CAATCTAAGTCTGTGCTCCTCCCTCGTTCTCGA-3'
(SEQ ID NO:22)

These oligomers were designed to provide Hind III and Kpn I restriction ends, respectively. The modified URA 3 transcription terminator was assembled by ligating all four oligomers to each other and digesting the ligation product with Hind III and Kpn I to produce ligatable Hind III-Kpn I restriction ends. The 67 base pair fragment was isolated on a polyacrylamide gel, purified by electroeluting the DNA from the gel fragment, and then ligated into Hind III-Kpn I restricted pUC118, (ATCC 37462). This construction created a new plasmid designated pARC304A.

50 A 67 base pair Hind III-Kpn I fragment containing a URA 3 transcription terminator was isolated from plasmid pARC304A and ligated into Hind III-Kpn I restricted pARC300E to form plasmid pARC300M. A truncated HMG-CoA reductase coding sequence was isolated as a 1667 base pair Bam HI-Ssp I fragment from pSOC611, (See Example 5) purified by agarose gel electrophoresis, and ligated to pARC300M, which had been restricted with Bam HI and Hinc II, to form plasmid pARC300R.

55 A URA 3 complementing gene was removed from plasmid pARC300Y as an Xma I restriction fragment, and ligated into the Xma I site of pARC300R to create plasmid pARC300U.

One other change in the restriction sites available on the DNA specifying the PGK promoter was made. The minimum DNA required to specify full PGK promoter activity has been determined, [Stanway, Nucleic Acids Research, 15:6855-6873 (1987)]. A new Eco RI site was added to the DNA specifying the PGK promoter at a

region just past the minimal 5' required DNA. The site was added by utilizing the oligonucleotide:

d5'-CTTTATGAGGGTAACATGAATTCAAGAAGG-3' (SEQ ID NO:23),

- 5 to mutagenize mARC1228 by the method of Kunkel et al., Proc. Natl. Acad. Sci. USA, 82:4778 (1985). This new M13 derivative was designated pARC306M.

A 1500 base pair phosphoglycerate kinase promoter (PGK) was removed from plasmid pARC306L (See Example 5) using Eco RI and Bgl II restriction enzymes. The PGK promoter fragment was purified by agarose gel electrophoresis and ligated to Eco RI and Bam HI restricted pARC300U, to form plasmid pARC300S.

- 10 A shortened PGK promoter (555 base pair fragment) was isolated from Eco RI and Bgl II restricted plasmid pARC306M and inserted into Eco RI-Bam HI digested plasmid pARC300U to form plasmid pARC300T.

The only difference between plasmid pARC300S and plasmid pARC300T is the length of the PGK promoter driving transcription of the truncated reductase coding sequence. A unique Eco RV restriction site found within the URA 3 gene allows the plasmids to be linearized and integrated via homologous recombination into the chromosomal URA 3 gene.

EXAMPLE 7: Construction of Plasmid pARC304S

- 20 Plasmid pARC304S (see Figure 9) was constructed to place the coding sequence of a truncated HMGI gene under the control of an ADH promoter.

Plasmid pBR322 was digested with Eco RI and Bam HI to yield a fragment containing the ADH1 promoter. The ADH1-containing fragment was ligated into plasmid pARC300U (See Example 6), which had been cut with Eco RI and Bam HI, to form pARC304S.

- 25 Plasmid pARC304S was deposited pursuant to the Budapest Treaty requirements with the American Type Culture Collection (ATCC) at 12301 Parklawn Drive, Rockville, MD 20852 U.S.A. on November 9, 1990 and was assigned Accession No. ATCC40916.

EXAMPLE 8: Generation of Mutant *S. cerevisiae* ATC0402mu

- 30 Mutant ATC0402mu was generated to have the GAL, a, and trp1 phenotype as well as having defects in the expression of zymosterol-24-methyltransferase and ergosta-5,7,24(28)-triol-22-dehydrogenase enzymes. These enzymes are respectively the erg6 and erg5 gene products of S. cerevisiae.

An erg6 deficient mutant S. cerevisiae, M610-12B, obtained from the Yeast Genetic Stock Center (Univ. of California, Berkeley, CA), was crossed with an erg5 deficient mutant S. cerevisiae (obtained as a gift from

- 35 Dr. Leo Parks, North Carolina State Univ., Raleigh, NC) to produce an erg6-erg5 double mutant, ATC0403mu.

ATC0403mu was then crossed with wild-type S. cerevisiae, DBY745 (Yeast Genetic Stock Center) to produce mutant ATC0402mu.

Mutant ATC0402mu was deposited pursuant to the Budapest Treaty Requirements with the American Type Culture Collection (ATCC) at 12301 Parklawn Drive, Rockville MD 20852 U.S.A. on November 9, 1990, and

- 40 was assigned Accession No. ATCC 74027.

EXAMPLE 9: Generation of Transformed Mutants ATC1500cp, ATC1502, ATC1503, ATC1551 and ATC2401

- 45 Several mutants were generated from the transformation of ATC0402mu using the method of Example 1, with various expression systems (plasmids) containing HMG-CoA reductase coding sequences under the transcriptional control of various promoters. The introduction into ATC0402mu of plasmid pSOC106ARC, constructed according to the method of Example 3, created ATC1503.

- The introduction into ATC0402mu of plasmid pSOC725ARC, constructed according to the method of Example 2, created ATC2401mu.

The introduction into ATC0402mu of plasmid pARC306E, constructed according to the method of Example 4, created ATC1502.

The introduction into ATC0402mu of plasmid pARC300D, constructed according to the method of Example 5, created ATC1500cp.

- 55 The creation of strain ATC1551 required the generation of a ura3 derivative of strain ATC1500cp, which has no auxotrophic markers. The ura3 derivative was created by transforming ATC1500cp with a mutagenic oligonucleotide using the method of Moerschell et al. [Proc. Natl. Acad. Sci. USA, 85:524-528 (1988)]. The sequence of the mutagenic oligonucleotide used is:

5' -GCCAAGTAGTTTACTCTCAAGACAGATAATTCGCTGACA-3'
(SEQ ID NO:24)

5 Mutated yeast cells were selected by their resistance to 5'-fluoro-orotic acid (5-FOA), as described in Ausubel et al., (eds.), Current Protocols In Molecular Biology, John Wiley and Sons, New York, (1989), and screened for their inability to grow in the absence of uracil. The resulting *ura3* strain was designated ATC0135rc. Strain ATC0315rc was then transformed with plasmid pARC304S, constructed according to the method of Example 7, to create strain ATC1551.

10 Transformation of strain ATC0315rc with plasmid pARC304S of the present invention resulted in the greatest degree of sterol accumulation. Further, the growth of a transformed ATC0315rc mutant under conditions of restricted aeration as compared to usual culture conditions, resulted in an increased accumulation of squalene relative to other sterols as well as an increase in the total accumulation of squalene and total sterols.

15 Mutant ATC0315rc was deposited pursuant to the Budapest Treaty Requirements with the American Type Culture Collection (ATCC) at 12301 Parklawn Drive, Rockville, MD 20852 U.S.A. on September 16, 1991, and was assigned Accession No. ATCC 74090.

EXAMPLE 10: Generation of Mutant *S. cerevisiae* ATC6118, ATC0501 and ATC6119

20 Mutants were obtained using an inducible "TY1-neo" transposon as the mutagenic agent, [Boeke, et al., Science, 239:280-282 (1989)].

25 Wild type *S. cerevisiae* JB518 was transformed with plasmid pJEF1105 [Boeke et al., Science, 239:280-282 (1989)], containing an inducible GAL-TY1neo expression cassette, and plasmid pCGS286, containing a GAL-lacZ control. The transformed yeast were then spread onto petri dishes containing two kinds of Xgal chromogenic indicator dye: synthetic dextrose (SD) agar media minus uracil and synthetic galactose (SG) agar media minus uracil. Yeast transformed with plasmid pJEF1105 appeared normal on dextrose but smaller than untransformed control yeast on galactose media.

30 The stability of plasmid pJEF1105 was confirmed by shuttling into E. coli for propagation and restriction analysis.

Once plasmid pJEF1105-transformed yeasts were shown to be competent, the pJEF1105 transformants were placed on SG-minus uracil agar at a density of no more than 1000 transformants per petri plate. The plates were incubated at 22°C for five days, during which the mutagenic transposition of the plasmid borne TY1-neo occurred. The transformants were then replica plated onto another SG-minus uracil plate and incubated another five days. Those colonies that survived were replica plated onto YEPD agar plates containing 100 units/ml of nystatin to select for sterol production and 100 units/ml of G418 (a neomycin analog) to select for the "neo" phenotype. Transformants that were both nystatin and G418 resistant were evaluated for sterol content and distribution using gas chromatographic and mass spectrographic analysis and then classified as to the specific sterol biosynthetic step affected by the mutation.

40 A yeast deficient in the enzyme episterol-5-dehydrogenase (the erg3 gene product) was isolated and designated ATC6118.

A yeast deficient in the enzyme zymosterol-24-methyltransferase (erg6) was isolated from plasmid pJEF1105 mutated yeast DBY745 (Yeast Genetic Stock Center) and designated ATC0501.

ATC0501 was crossed with ATC6118 to produce an erg3-erg6 double mutant designated ATC6119.

45 **EXAMPLE 11: Generation of Transformed Mutant *S. cerevisiae* ATC2100, ATC2104 and ATC2109**

Following the method of Example 1, the introduction into ATC6119 of plasmids pARC300S and pARC300T, constructed according to the method of Example 6, created ATC2100 and ATC2104 respectively, whereas the introduction into ATC6118 of plasmid pARC300S created ATC2109.

50 **EXAMPLE 12: Generation of Mutant *S. cerevisiae* ATC4124**

ATC4124 (Yeast Genetic Stock Centers) was generated by crossing ATC0403mu with YNN281 (Yeast Genetic Stock Centers) and selecting for the desired mutation. The resulting segregants were then backcrossed twice with YNN281.

55 Resulting ATC4124 had a defect in the expression of cholesta-5,7,24(28)-triol-22-dehydrogenase (the erg5 gene product).

EXAMPLE 13: Generation of Transformed Mutant *S. cerevisiae* ATC2107 and ATCE2108

Following the method of Example 1, introduction into ATC4124 of plasmid pARC306E, constructed according to the method of Example 4, created ATC2107 and ATC2108.

EXAMPLE 14: HMG-CoA Reductase Activity in Mutant and Transformed Yeast

HMG-CoA reductase activity was measured in non-transformed and transformed erg5-erg6 mutant yeasts. About 0.2 ml of 50 mM potassium phosphate buffer, pH 6.8, containing 125 mM sucrose, 20 mM EDTA and 100 mM KCl was combined with 10 mM DTT (freshly made), 1 mM NADPH, enzyme preparation and water to make an enzyme solution of about 0.475 ml final volume. The enzyme solution was preincubated at 37°C for 20 minutes and the incubation reaction initiated with the addition of 100 µM ¹⁴C-HMG-CoA (60,000 dpm in 0.025 ml). After five minutes, the reaction was stopped by the addition of 50 µl of HCl (1:1) and further incubation at 37°C for 30 minutes to lactonize the product. The product, mevalonolactone, was separated from HMG on an anion exchanger AGI-X8 (Bio-Rad) and the radioactivity associated with the product was counted in a scintillation counter. The results are shown in Table 5, below. The copy number of an added structural gene encoding a polypeptide having HMG-CoA reductase activity was estimated using standard procedures well known to those of skill in the transformation art.

TABLE 5

<u>Mutant</u>	<u>Estimated Copy # of Added Structural Gene</u>	<u>Specific Activity HMG-CoA Reductase (nmols/min/mg dry wt)</u>
<u>Non-transformed</u>		
ATC0402mu	0	0.52
<u>Transformed</u>		
ATC1503	1,2	0.69
ATC1500cp	5,6	1.33
ATC1512	8,9	1.01

EXAMPLE 15. Squalene and Sterol Accumulation in Yeast

The accumulation of squalene and specific sterols was determined in non-transformed and transformed mutant yeast cultures.

Fifty to one hundred mg of lyophilized yeast cells were extracted/saponified in 10 ml of an ethanol/water (2:1) solution containing 20 percent (w/v) KOH for two hours at 80°C. Extracts were partially neutralized with 10 ml 1N HCl and extracted twice with 15 ml n-heptane. The sterol-containing heptane fractions were evaporated to dryness under a stream of N₂ and resuspended to an appropriate volume with n-heptane containing an internal standard (5-alpha-cholestane).

The resuspended samples were analyzed for sterol accumulation by capillary GC with flame ionization detection.

Table 6 contains summary data for non-transformed (control) and transformed mutants having a single defect (erg3, erg5) in the expression of sterol biosynthetic pathway enzymes.

Table 7 contains summary data for non-transformed (control) and transformed mutants having double defects (erg3-erg6, erg5-erg6) in the expression of sterol biosynthetic pathway enzymes.

In both Table 6 and Table 7, the transformants were all made by transforming the control mutant having the same erg mutation.

Sterol levels are expressed as a percent of the dry biomass.

TABLE 6
ERG3 Mutants

<u>Sterol</u>	<u>Percent of Biomass</u>	
	<u>Non-transformed</u>	<u>Transformed</u>
	ATC6118	ATC2109
a. Squalene	N.D.*	0.26
b. ergosta-8,22-dienol	0.31	1.08
c. ergosta-7,22-dienol	0.66	1.64
d. ergosta-8-enol	0.27	0.42
e. ergosta-7-enol	0.63	0.72

ERG5 Mutants

<u>Sterol</u>	<u>Percent of Biomass</u>		
	<u>Non-transformed</u>	<u>Transformed</u>	
	ATC4124	ATC2107	ATC2108
a. Squalene	N.D.	1.10	0.49
b. Zymosterol	0.05	0.25	0.25
c. ergosta-5,7, 24(28)-trienol and ergosta-5,7-dienol	0.17	1.75	1.19

* Not Detectable

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TABLE 7
ERG3-ERG6 Mutants

Sterol	Percent of Biomass			
	Non-transformed	Transformed	ATC6119	ATC2100
N.D***				0.98
a. Squalene	0.21	1.10	1.10	1.80
b. Zymosterol	0.53	1.10	1.10	1.50
c. Cholesta-7, 24-dienol				

ERG5-ERG6 Mutants

Sterol	Percent of Biomass			
	Non-transformed	Transformed	ATC1503 (n=4)	ATC2401AU (n=4)
a. Squalene	0.026	0.947	1.078	0.27
b. Zymosterol	1.107	1.358	1.125	2.065
c. C5,7,24*	1.542	0.956	1.064	1.354
d. C7,24**	0.213	0.362	0.250	0.408

* C5,7,24 is cholesta-5,7,24-trienol

** C7,24 is cholesta-7,24-dienol

*** Not Detectable

n = number of observations

The above data illustrate that transformation of mutants having a single defect in the expression of sterol biosynthetic pathway enzymes resulted in an increased accumulation of squalene and specific sterols (See Table 6).

5 Relativ to a non-transformed erg3 mutant, erg3 mutants transformed with a plasmid vector useful in the present invention overaccumulated squalene, ergosta-8,22-dienol, ergosta-7,22-dienol, ergosta-8-enol and ergosta-7-enol.

Relative to a non-transformed erg5 mutant, erg5 mutants transformed with a plasmid vector useful in the present invention overaccumulated squalene, zymosterol, and a mixture of ergosta-5,7,24(28)-triol and ergosta-5,7-dienol.

10 Similarly, transformation of mutants having double defects in the sterol biosynthetic pathway enzymes led to the overaccumulation of squalene and specific sterols.

Relative to a non-transformed erg3-erg6 mutant, erg3-erg6 mutants transformed with a plasmid vector useful in the present invention overaccumulated squalene, zymosterol and cholesta-7,24-dienol.

15 Relative to a non-transformed erg5-erg6 mutant, erg5-erg6 double mutants transformed with a plasmid vector useful in the present invention overaccumulated squalene, zymosterol, cholesta-5,7,24-trienol and cholesta-7,24-dienol.

20 The greatest increases in squalene and specific sterol accumulation are seen when erg5-erg6 mutant ATC0315rc is transformed with plasmid vector PARC304S (mutant ATC1551), as described in Example 9. Further, the data show that species ATC0402mu, the grandparent strain of mutant ATC0315rc, has elevated levels of sterols relative to either an erg5 or an erg6 single mutant (see Table 6).

EXAMPLE: 16 Induction of Squalene Accumulation in Yeast Transformant ATC1551

It is generally known that restricted aeration induces squalene accumulation at the expense of sterols in yeast cultures. This occurs because oxygen is required for the enzymatic conversion of squalene to squalene monoepoxide, which in turn is converted into lanosterol and other yeast sterols.

25 To determine if high levels of squalene accumulation could be induced in transformants, cultures of ATC1551 were grown under varying degrees of aeration by varying the volume (and hence the surface-to-volume ratio) of growth medium in shake-flask cultures and assaying squalene and total sterol at one day intervals over a period of four days.

30 Triplicate 250 ml baffled shake-flasks respectively containing 50, 100, 150 and 200 ml of YEP/2 percent glucose growth medium were inoculated with two ml of a 24 hour liquid culture of ATC1551 grown on a rotary shaker (200 rpm) at 30°C. Fifty ml culture aliquots were harvested by centrifugation after one, two, three and four days growth under the aforementioned conditions and lyophilized overnight.

35 To insure efficient squalene extraction, approximately 100 mg of each lyophilized sample was agitated for 10 minutes in 15 ml conical tubes containing a suitable quantity of glass beads and a small amount of water. The disrupted cell material was then extracted three successive times with 10 ml of 100 percent ethanol with vigorous agitation for one hour at 80°C. The combined ethanol extracts were reduced to dryness under a stream of nitrogen and redissolved in two ml of heptane containing 5 α -cholestane as the internal standard. GC analyses of squalene were conducted as previously described.

40 For total sterol analyses, the same samples were reduced under a stream of nitrogen and saponified in 5 ml of 95 percent ethanol/water solution containing 0.3 M KOH for one hour at 80°C. An equivalent volume of water was added and the samples were twice extracted with 10 ml aliquots of heptane. The heptane extracts were combined, reduced to a suitable volume and analyzed by GC.

45 The results are shown in Table 8 (data averaged from triplicate cultures and expressed as percent of dry biomass).

Table 8

	Time to Harvest	<u>Growth Medium Volume</u>			
		50 ml	100 ml	150 ml	200 ml
5					
10	Day 1				
	squalene	4.25	5.40	3.61	2.63
	total sterol	9.40	9.52	6.81	5.46
15	Day 2				
	squalene	4.78	6.43	11.89	8.32
	total sterol	8.29	6.44	3.72	2.98
20	Day 3				
	squalene	4.75	8.82	13.54	13.38
	total sterol	7.96	7.65	4.36	4.19
25	Day 4				
	squalene	4.03	7.08	15.99	14.72
	total sterol	7.09	8.62	5.10	3.39

25 The data show that in transformed, erg5-erg6 mutants, squalene is preferentially accumulated as compared to total sterol by restricting the level of aeration as compared to usual culture conditions (50 ml of growth medium), particularly after more than about one day of culture. The data also show that restricting the level of aeration (lowering the surface-to-volume ratio) also increases the sum total of squalene and total sterol accumulation, after more than about two days of culture.

30 Although the present invention has now been described in terms of certain preferred embodiments, and exemplified with respect thereto, one skilled in the art will readily appreciate that various modifications, changes, omissions and substitutions may be made without departing from the spirit thereof.

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SEQUENCE LISTING

(1) GENERAL INFORMATION:

- (i) APPLICANT: Saunders, Court A.
10 Wolf, Fred R.
Mukharji, Indrani
- (ii) TITLE OF INVENTION: A Method and Composition for Increasing
the Accumulation of Squalene and Specific Sterols in
Yeast
15
- (iii) NUMBER OF SEQUENCES: 24
- (iv) CORRESPONDENCE ADDRESS:
20 (A) ADDRESSEE: Amoco Corp., Patents and Licensing Dept.
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- (v) COMPUTER READABLE FORM:
25 (A) MEDIUM TYPE: Floppy disk
(B) COMPUTER: IBM PC compatible
(C) OPERATING SYSTEM: PC-DOS/MS-DOS
(D) SOFTWARE: PatentIn Release #1.0, Version #1.25
- (vi) CURRENT APPLICATION DATA:
30 (A) APPLICATION NUMBER: 07/613,380
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- (viii) ATTORNEY/AGENT INFORMATION:
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40 (2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
45 (A) LENGTH: 3360 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: DNA (genomic)

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(ix) FEATURE:

- (A) NAME/KEY: CDS
 (B) LOCATION: 121..3282

10 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

TTTATTAAC TATTTTTTC TTCTTCTAC CCAATTCTAG TCAGGAAAG ACTAAGGGCT	60
GGAACATAGT GTATCATTGT CTAATTGTTG ATACAAAGTA GATAAATACA TAAAACAAGC	120
15 ATG CCG CCG CTA TTC AAG GGA CTG AAA CAG ATG GCA AAG CCA ATT GCC Met Pro Pro Leu Phe Lys Gly Leu Lys Gln Met Ala Lys Pro Ile Ala	168
1 5 10 15	
TAT GTT TCA AGA TTT TCG GCG AAA CGA CCA ATT CAT ATA ATA CTT TTT Tyr Val Ser Arg Phe Ser Ala Lys Arg Pro Ile His Ile Ile Leu Phe	216
20 25 30	
TCT CTA ATC ATA TCC GCA TTC GCT TAT CTA TCC GTC ATT CAG TAT TAC Ser Leu Ile Ile Ser Ala Phe Ala Tyr Leu Ser Val Ile Gln Tyr Tyr	264
35 40 45	
25 TTC AAT GGT TGG CAA CTA GAT TCA AAT AGT GTT TTT GAA ACT GCT CCA Phe Asn Gly Trp Gln Leu Asp Ser Asn Ser Val Phe Glu Thr Ala Pro	312
50 55 60	
30 AAT AAA GAC TCC AAC ACT CTA TTT CAA GAA TGT TCC CAT TAC TAC AGA Asn Lys Asp Ser Asn Thr Leu Phe Gln Glu Cys Ser His Tyr Tyr Arg	360
65 70 75 80	
35 GAT TCC TCT CTA GAT GGT TGG GTA TCA ATC ACC GCG CAT GAA GCT AGT Asp Ser Ser Leu Asp Gly Trp Val Ser Ile Thr Ala His Glu Ala Ser	408
85 90 95	
35 GAG TTA CCA GCC CCA CAC CAT TAC TAT CTA TTA AAC CTG AAC TTC AAT Glu Leu Pro Ala Pro His His Tyr Tyr Leu Leu Asn Leu Asn Phe Asn	456
100 105 110	
40 AGT CCT AAT GAA ACT GAC TCC ATT CCA GAA CTA GCT AAC ACG GTT TTT Ser Pro Asn Glu Thr Asp Ser Ile Pro Glu Leu Ala Asn Thr Val Phe	504
115 120 125	
45 GAG AAA GAT AAT ACA AAA TAT ATT CTG CAA GAA GAT CTC AGT GTT TCC Glu Lys Asp Asn Thr Lys Tyr Ile Leu Gln Glu Asp Leu Ser Val Ser	552
130 135 140	
45 AAA GAA ATT TCT TCT ACT GAT GGA ACG AAA TGG AGG TTA AGA AGT GAC Lys Glu Ile Ser Ser Thr Asp Gly Thr Lys Trp Arg Leu Arg Ser Asp	600
145 150 155 160	

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	AGA AAA AGT CTT TTC GAC GTA AAG ACG TTA GCA TAT TCT CTC TAC GAT Arg Lys Ser Leu Phe Asp Val Lys Thr Leu Ala Tyr Ser Leu Tyr Asp 165 170 175	648
10	GTA TTT TCA GAA AAT GTA ACC CAA GCA GAC CCG TTT GAC GTC CTT ATT Val Phe Ser Glu Asn Val Thr Gln Ala Asp Pro Phe Asp Val Leu Ile 180 185 190	696
15	ATG GTT ACT GCC TAC CTA ATG ATG TTC TAC ACC ATA TTC GGC CTC TTC Met Val Thr Ala Tyr Leu Met Met Phe Tyr Thr Ile Phe Gly Leu Phe 195 200 205	744
20	AAT GAC ATG AGG AAG ACC GGG TCA AAT TTT TGG TTG AGC GCC TCT ACA Asn Asp Met Arg Lys Thr Gly Ser Asn Phe Trp Leu Ser Ala Ser Thr 210 215 220	792
25	GTG GTC AAT TCT GCA TCA TCA CTT TTC TTA GCA TTG TAT GTC ACC CAA Val Val Asn Ser Ala Ser Ser Leu Phe Leu Ala Leu Tyr Val Thr Gln 225 230 235 240	840
30	TGT ATT CTA GGC AAA GAA GTT TCC GCA TTA ACT CTT TTT GAA GGT TTG Cys Ile Leu Gly Lys Glu Val Ser Ala Leu Thr Leu Phe Glu Gly Leu 245 250 255	888
35	CCT TTC ATT GTA GTT GTT GGT TTC AAG CAC AAA ATC AAG ATT GCC Pro Phe Ile Val Val Val Gly Phe Lys His Lys Ile Lys Ile Ala 260 265 270	936
40	CAG TAT GCC CTG GAG AAA TTT GAA AGA GTC GGT TTA TCT AAA AGG ATT Gln Tyr Ala Leu Glu Lys Phe Glu Arg Val Gly Leu Ser Lys Arg Ile 275 280 285	984
45	ACT ACC GAT GAA ATC GTT TTT GAA TCC GTG AGC GAA GAG GGT GGT CGT Thr Thr Asp Glu Ile Val Phe Glu Ser Val Ser Glu Glu Gly Gly Arg 290 295 300	1032
50	TTG ATT CAA GAC CAT TTG CTT TGT ATT TTT GCC TTT ATC GGA TGC TCT Leu Ile Gln Asp His Leu Leu Cys Ile Phe Ala Phe Ile Gly Cys Ser 305 310 315 320	1080
55	ATG TAT GCT CAC CAA TTG AAG ACT TTG ACA AAC TTC TGC ATA TTA TCA Met Tyr Ala His Gln Leu Lys Thr Leu Thr Asn Phe Cys Ile Leu Ser 325 330 335	1128
60	GCA TTT ATC CTA ATT TTT GAA TTG ATT TTA ACT CCT ACA TTT TAT TCT Ala Phe Ile Leu Ile Phe Glu Leu Ile Leu Thr Pro Thr Phe Tyr Ser 340 345 350	1176
65	GCT ATC TTA CGG CTT AGA CTG GAA ATG AAT GTT ATC CAC AGA TCT ACT Ala Ile Leu Ala Leu Arg Leu Glu Met Asn Val Ile His Arg Ser Thr 355 360 365	1224

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	ATT ATC AAG CAA ACA TTA GAA GAA GAC GGT GTT GTT CCA TCT ACA GCA Ile Ile Lys Gln Thr Leu Glu Glu Asp Gly Val Val Pro Ser Thr Ala 370 375 380	1272
10	AGA ATC ATT TCT AAA GCA GAA AAG AAA TCC GTA TCT TCT TTC TTA AAT Arg Ile Ile Ser Lys Ala Glu Lys Lys Ser Val Ser Ser Phe Leu Asn 385 390 395 400	1320
	CTC AGT GTG GTT GTC ATT ATC ATG AAA CTC TCT GTC ATA CTG TTG TTT Leu Ser Val Val Val Ile Ile Met Lys Leu Ser Val Ile Leu Leu Phe 405 410 415	1368
15	GTT TTC ATC AAC TTT TAT AAC TTT GGT GCA AAT TGG GTC AAT GAT GCC Val Phe Ile Asn Phe Tyr Asn Phe Gly Ala Asn Trp Val Asn Asp Ala 420 425 430	1416
20	TTC AAT TCA TTG TAC TTC GAT AAG GAA CGT GTT TCT CTA CCA GAT TTT Phe Asn Ser Leu Tyr Phe Asp Lys Glu Arg Val Ser Leu Pro Asp Phe 435 440 445	1464
	ATT ACC TCG AAT GCC TCT GAA AAC TTT AAA GAG CAA GCT ATT GTT AGT Ile Thr Ser Asn Ala Ser Glu Asn Phe Lys Glu Gln Ala Ile Val Ser 450 455 460	1512
25	GTC ACC CCA TTA TTA TAT TAC AAA CCC ATT AAG TCC TAC CAA CGC ATT Val Thr Pro Leu Leu Tyr Tyr Lys Pro Ile Lys Ser Tyr Gln Arg Ile 465 470 475 480	1560
30	GAG GAT ATG GTT CTT CTA TTG CTT CGT AAT GTC AGT GTT GCC ATT CGT Glu Asp Met Val Leu Leu Leu Arg Asn Val Ser Val Ala Ile Arg 485 490 495	1608
	GAT AGG TTC GTC AGT AAA TTA GTT CTT TCC GCC TTA GTA TGC AGT GCT Asp Arg Phe Val Ser Lys Leu Val Leu Ser Ala Leu Val Cys Ser Ala 500 505 510	1656
35	GTC ATC AAT GTG TAT TTA TTG AAT GCT GCT AGA ATT CAT ACC AGT TAT Val Ile Asn Val Tyr Leu Leu Asn Ala Ala Arg Ile His Thr Ser Tyr 515 520 525	1704
	ACT GCA GAC CAA TTG GTG AAA ACT GAA GTC ACC AAG AAG TCT TTT ACT Thr Ala Asp Gln Leu Val Lys Thr Glu Val Thr Lys Lys Ser Phe Thr 530 535 540	1752
40	GCT CCT GTA CAA AAG GCT TCT ACA CCA GTT TTA ACC AAT AAA ACA GTC Ala Pro Val Gln Lys Ala Ser Thr Pro Val Leu Thr Asn Lys Thr Val 545 550 555 560	1800
45	ATT TCT GGA TCG AAA GTC AAA AGT TTA TCA TCT GCG CAA TCG AGC TCA Ile Ser Gly Ser Lys Val Lys Ser Leu Ser Ser Ala Gln Ser Ser Ser 565 570 575	1848

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	TCA GGA CCT TCA TCA TCT ACT GAG GAA GAT GAT TCC CGC GAT ATT GAA Ser Gly Pro Ser Ser Ser Ser Glu Glu Asp Asp Ser Arg Asp Ile Glu 580 585 590	1896
10	AGC TTG GAT AAG AAA ATA CGT CCT TTA GAA GAA TTA GAA GCA TTA TTA Ser Leu Asp Lys Lys Ile Arg Pro Leu Glu Glu Leu Glu Ala Leu Leu 595 600 605	1944
15	AGT AGT CGA AAT ACA AAA CAA TTG AAG AAC AAA GAG GTC GCT GCC TTG Ser Ser Gly Asn Thr Lys Gln Leu Lys Asn Lys Glu Val Ala Ala Leu 610 615 620	1992
	GTT ATT CAC GGT AAG TTA CCT TTG TAC GCT TTG GAG AAA AAA TTA GGT Val Ile His Gly Lys Leu Pro Leu Tyr Ala Leu Glu Lys Lys Leu Gly 625 630 635 640	2040
20	GAT ACT ACG AGA GCG GTT GCG GTA CGT AGG AAG GCT CTT TCA ATT TTG Asp Thr Thr Arg Ala Val Ala Val Arg Arg Lys Ala Leu Ser Ile Leu 645 650 655	2088
	GCA GAA GCT CCT GTA TTA GCA TCT GAT CGT TTA CCA TAT AAA AAT TAT Ala Glu Ala Pro Val Leu Ala Ser Asp Arg Leu Pro Tyr Lys Asn Tyr 660 665 670	2136
25	GAC TAC GAC CGC GTA TTT GGC GCT TGT TGT GAA AAT GTT ATA GGT TAC Asp Tyr Asp Arg Val Phe Gly Ala Cys Cys Glu Asn Val Ile Gly Tyr 675 680 685	2184
30	ATG CCT TTG CCC GTT GGT GTT ATA GGC CCC TTG GTT ATC GAT GGT ACA Met Pro Leu Pro Val Gly Val Ile Gly Pro Leu Val Ile Asp Gly Thr 690 695 700	2232
	TCT TAT CAT ATA CCA ATG GCA ACT ACA GAG GGT TGT TTG GTA GCT TCT Ser Tyr His Ile Pro Met Ala Thr Thr Glu Gly Cys Leu Val Ala Ser 705 710 715 720	2280
35	GCC ATG CGT GGC TGT AAG GCA ATC AAT GCT GGC GGT GGT GCA ACA ACT Ala Met Arg Gly Cys Lys Ala Ile Asn Ala Gly Gly Gly Ala Thr Thr 725 730 735	2328
	GTT TTA ACT AAG GAT GGT ATG ACA AGA GGC CCA GTA GTC CGT TTC CCA Val Leu Thr Lys Asp Gly Met Thr Arg Gly Pro Val Val Arg Phe Pro 740 745 750	2376
40	ACT TTG AAA AGA TCT GGT GCC TGT AAG ATA TGG TTA GAC TCA GAA GAG Thr Leu Lys Arg Ser Gly Ala Cys Ile Trp Leu Asp Ser Glu Glu 755 760 765	2424
45	GGA CAA AAC GCA ATT AAA AAA GCT TTT AAC TCT ACA TCA AGA TTT GCA Gly Gln Asn Ala Ile Lys Lys Ala Phe Asn Ser Thr Ser Arg Phe Ala 770 775 780	2472

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	CGT CTG CAA CAT ATT CAA ACT TGT CTA GCA GGA GAT TTA CTC TTC ATG Arg Leu Gln His Ile Gln Thr Cys Leu Ala Gly Asp Leu Leu Phe Met 785 790 795 800	2520
10	AGA TTT AGA ACA ACT ACT GGT GAC GCA ATG GGT ATG AAT ATG ATT TCT Arg Phe Arg Thr Thr Gly Asp Ala Met Gly Met Asn Met Ile Ser 805 810 815	2568
	AAA GGT GTC GAA TAC TCA TTA AAG CAA ATG GTA GAA GAG TAT GGC TGG Lys Gly Val Glu Tyr Ser Leu Lys Gln Met Val Glu Glu Tyr Gly Trp 820 825 830	2616
15	GAA GAT ATG GAG GTT GTC TCC GTT TCT GGT AAC TAC TGT ACC GAC AAA Glu Asp Met Glu Val Val Ser Val Ser Gly Asn Tyr Cys Thr Asp Lys 835 840 845	2664
20	AAA CCA GCT GCC ATC AAC TGG ATC GAA GGT CGT GGT AAG AGT GTC GTC Lys Pro Ala Ala Ile Asn Trp Ile Glu Gly Arg Gly Lys Ser Val Val 850 855 860	2712
	GCA GAA GCT ACT ATT CCT GGT GAT GTT GTC AGA AAA GTG TTA AAA ACT Ala Glu Ala Thr Ile Pro Gly Asp Val Val Arg Lys Val Leu Lys Ser 865 870 875 880	2760
25	GAT GTT TCC GCA TTG GTT GAG TTG AAC ATT GCT AAG AAT TTG GTT GGA Asp Val Ser Ala Leu Val Glu Leu Asn Ile Ala Lys Asn Leu Val Gly 885 890 895	2808
30	TCT GCA ATG GCT GGG TCT GTT GGT GGA TTT AAC GCA CAT GCA GCT AAT Ser Ala Met Ala Gly Ser Val Gly Gly Phe Asn Ala His Ala Ala Asn 900 905 910	2856
	TTA GTG ACA GCT GTT TTC TTG GCA TTA GGA CAA GAT CCT GCA CAA AAT Leu Val Thr Ala Val Phe Leu Ala Leu Gly Gln Asp Pro Ala Gln Asn 915 920 925	2904
35	GTT GAA AGT TCC AAC TGT ATA ACA TTG ATG AAA GAA GTG GAC GGT GAT Val Glu Ser Ser Asn Cys Ile Thr Leu Met Lys Glu Val Asp Gly Asp 930 935 940	2952
	TTG AGA ATT TCC GTC TCC ATG CCA TCC ATC GAA GTA GGT ACC ATC GGT Leu Arg Ile Ser Val Met Pro Ser Ile Glu Val Gly Thr Ile Gly 945 950 955 960	3000
40	GGT GGT ACT GTT CTA GAA CCA CAA GGT GCC ATG TTG GAC TTA TTA GGT Gly Gly Thr Val Leu Glu Pro Gln Gly Ala Met Leu Asp Leu Leu Gly 965 970 975	3048
45	GTA AGA GGC CCG CAT GCT ACC GCT CCT GGT ACC AAC GCA CGT CAA TTA Val Arg Gly Pro His Ala Thr Ala Pro Gly Thr Asn Ala Arg Gln Leu 980 985 990	3096

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GCA AGA ATA GTT GCC TGT CCC GTC TTG GCA GGT GAA TTA TCC TTA TGT Ala Arg Ile Val Ala Cys Ala Val Leu Ala Gly Glu Leu Ser Leu Cys 995 1000 1005	3144
GCT GCC CTA GCA CCC GGC CAT TTG GTT CAA AGT CAT ATG ACC CAC AAC Ala Ala Leu Ala Ala Gly His Leu Val Gln Ser His Met Thr His Asn 1010 1015 1020	3192
AGG AAA CCT GCT GAA CCA ACA AAA CCT AAC AAT TTG GAC GCC ACT GAT Arg Lys Pro Ala Glu Pro Thr Lys Pro Asn Asn Leu Asp Ala Thr Asp 1025 1030 1035 1040	3240
ATA AAT CGT TTG AAA GAT GGG TCC GTC ACC TGC ATT AAA TCC Ile Asn Arg Leu Lys Asp Gly Ser Val Thr Cys Ile Lys Ser 1045 1050	3282
TAAACTTAGT CATACTCAT TGGTATTCTC TTGAAAAAGA AGCACAAACAG CACCATGTGT	3342
TACGTAAAAT ATTTACTT	3360

(2) INFORMATION FOR SEQ ID NO:2:

25 (i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 1054 amino acids
 (B) TYPE: amino acid
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

30 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Pro Pro Leu Phe Lys Gly Leu Lys Gln Met Ala Lys Pro Ile Ala 1 5 10 15
Tyr Val Ser Arg Phe Ser Ala Lys Arg Pro Ile His Ile Ile Leu Phe 20 25 30
Ser Leu Ile Ile Ser Ala Phe Ala Tyr Leu Ser Val Ile Gln Tyr Tyr 35 40 45
Phe Asn Gly Trp Gln Leu Asp Ser Asn Ser Val Phe Glu Thr Ala Pro 50 55 60
Asn Lys Asp Ser Asn Thr Leu Phe Gln Glu Cys Ser His Tyr Tyr Arg 65 70 75 80
Asp Ser Ser Leu Asp Gly Trp Val Ser Ile Thr Ala His Glu Ala Ser 85 90 95
45 Glu Leu Pro Ala Pro His His Tyr Tyr Leu Leu Asn Leu Asn Phe Asn 100 105 110

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5 Ser Pro Asn Glu Thr Asp Ser Ile Pr Glu Leu Ala Asn Thr Val Phe
 115 120 125

 10 Glu Lys Asp Asn Thr Lys Tyr Ile Leu Gln Glu Asp Leu Ser Val Ser
 130 135 140

 15 Lys Glu Ile Ser Ser Thr Asp Gly Thr Lys Trp Arg Leu Arg Ser Asp
 145 150 155 160

 20 Arg Lys Ser Leu Phe Asp Val Lys Thr Leu Ala Tyr Ser Leu Tyr Asp
 165 170 175

 25 Val Phe Ser Glu Asn Val Thr Gln Ala Asp Pro Phe Asp Val Leu Ile
 180 185 190

 30 Met Val Thr Ala Tyr Leu Met Met Phe Tyr Thr Ile Phe Gly Leu Phe
 195 200 205

 35 Asn Asp Met Arg Lys Thr Gly Ser Asn Phe Trp Leu Ser Ala Ser Thr
 210 215 220

 40 Val Val Asn Ser Ala Ser Ser Leu Phe Leu Ala Leu Tyr Val Thr Gln
 225 230 235 240

 45 Cys Ile Leu Gly Lys Glu Val Ser Ala Leu Thr Leu Phe Glu Gly Leu
 245 250 255

 50 Pro Phe Ile Val Val Val Gly Phe Lys His Lys Ile Lys Ile Ala
 260 265 270

 55 Gln Tyr Ala Leu Glu Lys Phe Glu Arg Val Gly Leu Ser Lys Arg Ile
 275 280 285

 60 Thr Thr Asp Glu Ile Val Phe Glu Ser Val Ser Glu Glu Gly Gly Arg
 290 295 300

 65 Leu Ile Gln Asp His Leu Leu Cys Ile Phe Ala Phe Ile Gly Cys Ser
 305 310 315 320

 70 Met Tyr Ala His Gln Leu Lys Thr Leu Thr Asn Phe Cys Ile Leu Ser
 325 330 335

 75 Ala Phe Ile Leu Ile Phe Glu Leu Ile Leu Thr Pro Thr Phe Tyr Ser
 340 345 350

 80 Ala Ile Leu Ala Leu Arg Leu Glu Met Asn Val Ile His Arg Ser Thr
 355 360 365

 85 Ile Ile Lys Gln Thr Leu Glu Glu Asp Gly Val Val Pro Ser Thr Ala
 370 375 380

5 Arg Ile Ile Ser Lys Ala Glu Lys Lys Ser Val Ser Ser Phe Leu Asn
 385 390 395 400
 Leu Ser Val Val Val Ile Ile Met Lys Leu Ser Val Ile Leu Leu Phe
 405 410 415
 10 Val Phe Ile Asn Phe Tyr Asn Phe Gly Ala Asn Trp Val Asn Asp Ala
 420 425 430
 Phe Asn Ser Leu Tyr Phe Asp Lys Glu Arg Val Ser Leu Pro Asp Phe
 435 440 445
 15 Ile Thr Ser Asn Ala Ser Glu Asn Phe Lys Glu Gln Ala Ile Val Ser
 450 455 460
 Val Thr Pro Leu Leu Tyr Tyr Lys Pro Ile Lys Ser Tyr Gln Arg Ile
 465 470 475 480
 20 Glu Asp Met Val Leu Leu Leu Leu Arg Asn Val Ser Val Ala Ile Arg
 485 490 495
 Asp Arg Phe Val Ser Lys Leu Val Leu Ser Ala Leu Val Cys Ser Ala
 500 505 510
 25 Val Ile Asn Val Tyr Leu Leu Asn Ala Ala Arg Ile His Thr Ser Tyr
 515 520 525
 Thr Ala Asp Gln Leu Val Lys Thr Glu Val Thr Lys Lys Ser Phe Thr
 530 535 540
 30 Ala Pro Val Gln Lys Ala Ser Thr Pro Val Leu Thr Asn Lys Thr Val
 545 550 555 560
 Ile Ser Gly Ser Lys Val Lys Ser Leu Ser Ser Ala Gln Ser Ser Ser
 35 565 570 575
 Ser Gly Pro Ser Ser Ser Glu Glu Asp Asp Ser Arg Asp Ile Glu
 580 585 590
 40 Ser Leu Asp Lys Lys Ile Arg Pro Leu Glu Glu Leu Glu Ala Leu Leu
 595 600 605
 Ser Ser Gly Asn Thr Lys Gln Leu Lys Asn Lys Glu Val Ala Ala Leu
 610 615 620
 45 Val Ile His Gly Lys Leu Pro Leu Tyr Ala Leu Glu Lys Lys Leu Gly
 625 630 635 640
 Asp Thr Thr Arg Ala Val Ala Val Arg Arg Lys Ala Leu Ser Ile Leu
 645 650 655
 50 Ala Glu Ala Pro Val Leu Ala Ser Asp Arg Leu Pro Tyr Lys Asn Tyr

	660	665	670
5	Asp Tyr Asp Arg Val Phe Gly Ala Cys Cys Glu Asn Val Ile Gly Tyr 675 680 685		
10	Met Pro Leu Pro Val Gly Val Ile Gly Pro Leu Val Ile Asp Gly Thr 690 695 700		
15	Ser Tyr His Ile Pro Met Ala Thr Thr Glu Gly Cys Leu Val Ala Ser 705 710 715 720		
20	Ala Met Arg Gly Cys Lys Ala Ile Asn Ala Gly Gly Ala Thr Thr 725 730 735		
25	Val Leu Thr Lys Asp Gly Met Thr Arg Gly Pro Val Val Arg Phe Pro 740 745 750		
30	Thr Leu Lys Arg Ser Gly Ala Cys Lys Ile Trp Leu Asp Ser Glu Glu 755 760 765		
35	Gly Gln Asn Ala Ile Lys Lys Ala Phe Asn Ser Thr Ser Arg Phe Ala 770 775 780		
40	Arg Leu Gln His Ile Gln Thr Cys Leu Ala Gly Asp Leu Leu Phe Met 785 790 795 800		
45	Arg Phe Arg Thr Thr Gly Asp Ala Met Gly Met Asn Met Ile Ser 805 810 815		
50	Lys Gly Val Glu Tyr Ser Leu Lys Gln Met Val Glu Glu Tyr Gly Trp 820 825 830		
	Glu Asp Met Glu Val Val Ser Val Ser Gly Asn Tyr Cys Thr Asp Lys 835 840 845		
	Lys Pro Ala Ala Ile Asn Trp Ile Glu Gly Arg Gly Lys Ser Val Val 850 855 860		
	Ala Glu Ala Thr Ile Pro Gly Asp Val Val Arg Lys Val Leu Lys Ser 865 870 875 880		
	Asp Val Ser Ala Leu Val Glu Leu Asn Ile Ala Lys Asn Leu Val Gly 885 890 895		
	Ser Ala Met Ala Gly Ser Val Gly Gly Phe Asn Ala His Ala Ala Asn 900 905 910		
	Leu Val Thr Ala Val Phe Leu Ala Leu Gly Gln Asp Pro Ala Gln Asn 915 920 925		
	Val Glu Ser Ser Asn Cys Ile Thr Leu Met Lys Glu Val Asp Gly Asp 930 935 940		

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Leu Arg Ile Ser Val Ser Met Pro Ser Ile Glu Val Gly Thr Ile Gly
 945 950 955 960

Gly Gly Thr Val Leu Glu Pro Gln Gly Ala Met Leu Asp Leu Leu Gly
 965 970 975

10 Val Arg Gly Pro His Ala Thr Ala Pro Gly Thr Asn Ala Arg Gln Leu
 980 985 990

Ala Arg Ile Val Ala Cys Ala Val Leu Ala Gly Glu Leu Ser Leu Cys
 995 1000 1005

15 Ala Ala Leu Ala Ala Gly His Leu Val Gln Ser His Met Thr His Asn
 1010 1015 1020

Arg Lys Pro Ala Glu Pro Thr Lys Pro Asn Asn Leu Asp Ala Thr Asp
 1025 1030 1035 1040

20 Ile Asn Arg Leu Lys Asp Gly Ser Val Thr Cys Ile Lys Ser
 1045 1050

(2) INFORMATION FOR SEQ ID NO:3:

25 (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 4768 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

30 (ii) MOLECULE TYPE: cDNA

(ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 164..2827

35 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

TGTATGTCTT GTCTTTCTCC TAAGGGCGT AGGTCATTG ATAACTCATG TCCTCACCTT 60

GCACCTCCCTT TGGAATTATT TGGTTTGAGT GAAGAAGACC GGACCTTCGA GGTCGCAAC 120

40 TTAAACAATA GACTTGTGAG GATCCAGGGA CCCAGTGGCT ACA ATG TTG TCA CGA 175
 Met Leu Ser Arg
 1

45 CTT TTC CGT ATG CAT GGC CTC TTT GTG GCC TCC CAT CCC TGG GAA GTT 223
 Leu Phe Arg Met His Gly Leu Phe Val Ala Ser His Pro Trp Glu Val
 5 10 15 20

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ATT GTG GGG ACG GTG ACA CTT ACC ATC TGT ATG ATG TCC ATG AAC ATG Ile Val Gly Thr Val Thr Leu Thr Ile Cys Met Met Ser Met Asn Met 25 30 35	271
TTC ACT GGC AAC AAC AAG ATC TGT GGT TGG AAT TAC GAG TGC CCA AAA Phe Thr Gly Asn Asn Lys Ile Cys Gly Trp Asn Tyr Glu Cys Pro Lys 40 45 50	319
TTT GAG GAG GAT GTA TTG AGC AGT GAC ATC ATC ATC CTC ACC ATA ACA Phe Glu Glu Asp Val Leu Ser Ser Asp Ile Ile Ile Leu Thr Ile Thr 55 60 65	367
CGG TGC ATC GCC ATC CTG TAC ATT TAC TTC CAG TTC CAG AAC TTA CGT Arg Cys Ile Ala Ile Leu Tyr Ile Tyr Phe Gln Phe Gln Asn Leu Arg 70 75 80	415
CAG CTT GGG TCG AAG TAT ATT TTA GGT ATT GCT GGC CTG TTC ACA ATT Gln Leu Gly Ser Lys Tyr Ile Leu Gly Ile Ala Gly Leu Phe Thr Ile 85 90 95 100	463
TTC TCA AGT TTT GTC TTT AGT ACA GTC GTC ATT CAC TTC TTA GAC AAA Phe Ser Ser Phe Val Phe Ser Thr Val Val Ile His Phe Leu Asp Lys 105 110 115	511
GAA CTG ACC GGC TTA AAT GAA GCT TTG CCC TTT TTC CTG CTT TTG ATT Glu Leu Thr Gly Leu Asn Glu Ala Leu Pro Phe Phe Leu Leu Ile 120 125 130	559
GAC CTT TCT AGA GCG AGT GCA CTA GCA AAG TTT GCC CTA AGT TCA AAC Asp Leu Ser Arg Ala Ser Ala Leu Ala Lys Phe Ala Leu Ser Ser Asn 135 140 145	607
TCT CAG GAT GAA GTA AGG GAA AAT ATA GCT CGC GGA ATG GCA ATT CTG Ser Gln Asp Glu Val Arg Glu Asn Ile Ala Arg Gly Met Ala Ile Leu 150 155 160	655
GGC CCC ACA TTC ACC CTT GAT GCT CTT GTG GAA TGT CTT GTA ATT GGA Gly Pro Thr Phe Thr Leu Asp Ala Leu Val Glu Cys Leu Val Ile Gly 165 170 175 180	703
GTT GGC ACC ATG TCA GGG GTG CGT CAG CTT GAA ATC ATG TGC TGC TTT Val Gly Thr Met Ser Gly Val Arg Gln Leu Glu Ile Met Cys Cys Phe 185 190 195	751
GGC TGC ATG TCT GTG CTT GCC AAC TAC TTC GTG TTC ATG ACA TTT TTC Gly Cys Met Ser Val Leu Ala Asn Tyr Phe Val Phe Met Thr Phe Phe 200 205 210	799
CCA GCG TGT GTG TCC CTG GTC CTT GAG CTT TCT CGG GAA AGT CGA GAG Pro Ala Cys Val Ser Leu Val Leu Glu Leu Ser Arg Glu Ser Arg Glu 215 220 225	847

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5	GGT CGT CCA ATT TCG CAG CTT AGC CAT TTT GCC CGA GTT TTG GAA GAA Gly Arg Pro Ile Trp Gln Leu Ser His Phe Ala Arg Val Leu Glu Glu 230 235 240	895
10	GAA GAG ATT AAA CCA AAC CCT GTA ACC CAA AGG GTC AAG ATG ATT ATG Glu Glu Asn Lys Pro Asn Pro Val Thr Gln Arg Val Lys Met Ile Met 245 250 255 260	943
	TCT TTA CGT TTG GTT CTT GPT CAT GCT CAC AGT CGA TGG ATA GCT GAT Ser Leu Gly Leu Val Leu Val His Ala His Ser Arg Trp Ile Ala Asp 265 270 275	991
15	CCT TCC CCT CAG AAT AGC ACA ACA GAA CAT TCT AAA GTC TCC TTG CGA Pro Ser Pro Gln Asn Ser Thr Thr Glu His Ser Lys Val Ser Leu Gly 280 285 290	1039
20	CTG GAT GAA GAT GTG TCC AAC AGA ATT GAA CCA AGT GTT TCT CTC TGG Leu Asp Glu Asp Val Ser Lys Arg Ile Glu Pro Ser Val Ser Leu Trp 295 300 305	1087
	CAG TTT TAT CTC TCC AAG ATG ATC ACC ATG GAC ATT GAA CAA GTG GTT Gln Phe Tyr Leu Ser Lys Met Ile Ser Met Asp Ile Glu Gln Val Val 310 315 320	1135
25	ACC CTG AGC TTA GCT TTT CTG TTG GCT GTC AAG TAC ATT TTC TTT GAA Thr Leu Ser Leu Ala Phe Leu Leu Ala Val Lys Tyr Ile Phe Phe Glu 325 330 335 340	1183
30	CAA GCA GAG ACA GAG TCC ACA CTG TCT TTA AAA AAT CCT ATC ACG TCT Gln Ala Glu Thr Glu Ser Thr Leu Ser Leu Lys Asn Pro Ile Thr Ser 345 350 355	1231
	CCT GTC GTG ACC CCA AAG AAA GCT CCA GAC AAC TGT TGT AGA CGG GAG Pro Val Val Thr Pro Lys Lys Ala Pro Asp Asn Cys Cys Arg Arg Glu 360 365 370	1279
35	CCT CTG CTT GTG AGA AGG AGC GAG AAG CTT TCA TCG GTT GAG GAG GAG Pro Leu Leu Val Arg Arg Ser Glu Lys Leu Ser Ser Val Glu Glu Glu 375 380 385	1327
	CCT GGG GTG AGC CAA GAT AGA AAA GTT GAG GTT ATA AAA CCA TTA GTG Pro Gly Val Ser Gln Asp Arg Lys Val Glu Val Ile Lys Pro Leu Val 390 395 400	1375
40	GTC GAA ACT GAG AGT GCA AGC AGA GCT ACA TTT GTG CTT GGC GCC TCT Val Glu Thr Glu Ser Ala Ser Arg Ala Thr Phe Val Leu Gly Ala Ser 405 410 415 420	1423
45	GGG ACC AGC CCT CCA GTG GCA GCG AGG ACA CAG GAG CTT GAA ATT GAA Gly Thr Ser Pro Pro Val Ala Ala Arg Thr Gln Glu Leu Glu Ile Glu 425 430 435	1471

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	CTC CCC ACT GAG CCT CGG CCT AAT GAA GAA TGT CTG CAG ATA CTG GAG Leu Pro Ser Glu Pro Arg Pro Asn Glu Glu Cys Leu Gln Ile Leu Glu 440 445 450	1519
10	AGT GCC GAG AAA GGT GCA AAG TTC CTT AGC GAT GCA GAG ATC ATC CAG Ser Ala Glu Lys Gly Ala Lys Phe Leu Ser Asp Ala Glu Ile Ile Gln 455 460 465	1567
15	TTC GTC AAT GCC AAG CAC ATC CCA GCC TAC AAA TTG GAA ACC TTA ATG Leu Val Asn Ala Lys His Ile Pro Ala Tyr Lys Leu Glu Thr Leu Met 470 475 480	1615
20	GAA ACT CAT GAA CGT GGT GTA TCT ATT CGC CGG CAG CTC CTC TCC ACA Glu Thr His Glu Arg Gly Val Ser Ile Arg Arg Gln Leu Leu Ser Thr 485 490 495 500	1663
25	AAG CTT CCA GAG CCT TCT CTG CAG TAC CTG CCT TAC AGA GAT TAT Lys Leu Pro Glu Pro Ser Ser Leu Gln Tyr Leu Pro Tyr Arg Asp Tyr 505 510 515	1711
30	AAT TAT TCC CTG GTG ATG GGA GCT TGC TGT GAG AAT GTG ATC GGA TAT Asn Tyr Ser Leu Val Met Gly Ala Cys Cys Glu Asn Val Ile Gly Tyr 520 525 530	1759
35	ATG CCC ATC CCT GTC GGA GTA GCA GGG CCT CTG TGC CTG GAT GGT AAA Met Pro Ile Pro Val Gly Val Ala Gly Pro Leu Cys Leu Asp Gly Lys 535 540 545	1807
40	GAG TAC CAG GTT CCA ATG GCA ACA ACG GAA GGC TGT CTG GTG GCC AGC Glu Tyr Gln Val Pro Met Ala Thr Thr Glu Gly Cys Leu Val Ala Ser 550 555 560	1855
45	ACC AAC AGA GGC TGC AGG GCA ATA GGT CTT GGT GGA GGT GCC AGC AGC Thr Asn Arg Gly Cys Arg Ala Ile Gly Leu Gly Gly Ala Ser Ser 565 570 575 580	1903
	CGG GTC CTT GCA GAT GGG ATG ACC CGG GGC CCA GTG GTG CGT CTT CCT Arg Val Leu Ala Asp Gly Met Thr Arg Gly Pro Val Val Arg Leu Pro 585 590 595	1951
	CGT GCT TGT GAT TCT GCA GAA GTG AAG GCC TGG CTT GAA ACA CCC GAA Arg Ala Cys Asp Ser Ala Glu Val Lys Ala Trp Leu Glu Thr Pro Glu 600 605 610	1999
	GGG TTT GCG GTG ATA AAG GAC GCC TTC GAT AGC ACT AGC AGA TTT GCA Gly Phe Ala Val Ile Lys Asp Ala Phe Asp Ser Thr Ser Arg Phe Ala 615 620 625	2047
	CGT CTA CAG AAG CTT CAT GTG ACC ATG GCA GGG CGC AAC CTG TAC ATC Arg Leu Gln Lys Leu His Val Thr Met Ala Gly Arg Asn Leu Tyr Ile 630 635 640	2095

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	CGT TTC CAG TCC AAG ACA GGG GAT GCC ATG GGG ATG AAC ATG ATT TCC Arg Phe Gln Ser Lys Thr Gly Asp Ala Met Gly Met Asn Met Ile Ser 645 650 655 660	2143
10	AAG GGC ACT GAG AAA GCA CTT CTG AAG CTT CAG GAG TTC TTT CCT GAA Lys Gly Thr Glu Lys Ala Leu Leu Lys Leu Gln Glu Phe Phe Pro Glu 665 670 675	2191
15	ATG CAG ATT CTG GCA GTT AGT GGT AAC TAC TGC ACT GAC AAG AAA CCT Met Gln Ile Leu Ala Val Ser Gly Asn Tyr Cys Thr Asp Lys Lys Pro 680 685 690	2239
20	GCC GCC ATA AAC TGG ATC GAG GGA AGA GGA AAG ACA GTT GTG TGT GAA Ala Ala Ile Asn Trp Ile Glu Gly Arg Gly Lys Thr Val Val Cys Glu 695 700 705	2287
25	GCT GTT ATT CCA GCC AAG GTG GTG AGA GAA GTA TTA AAG ACA ACT ACG Ala Val Ile Pro Ala Lys Val Val Arg Glu Val Leu Lys Thr Thr Thr 710 715 720	2335
30	GAA GCT ATG ATT GAC GTA AAC ATT AAC AAG AAT CTT GTG GGT TCT GCC Glu Ala Met Ile Asp Val Asn Ile Asn Lys Asn Leu Val Gly Ser Ala 725 730 735 740	2383
35	ATG GCT GGG AGC ATA GGA GGC TAC ATT GCC CAT GCA GCA AAC ATC GTC Met Ala Gly Ser Ile Gly Gly Tyr Asn Ala His Ala Asn Ile Val 745 750 755	2431
40	ACT GCT ATC TAC ATT GCA TGT GGC CAG GAT GCA GCA CAG AAT GTG GGG Thr Ala Ile Tyr Ile Ala Cys Gly Gln Asp Ala Ala Gln Asn Val Gly 760 765 770	2479
45	AGT TCA AAC TGT ATT ACT TTA ATG GAA GCA AGT GGT CCC ACG AAT GAA Ser Ser Asn Cys Ile Thr Leu Met Glu Ala Ser Gly Pro Thr Asn Glu 775 780 785	2527
50	GAC TTG TAT ATC AGC TGC ACC ATG CCA TCT ATA GAG ATA GGA ACT GTG Asp Leu Tyr Ile Ser Cys Thr Met Pro Ser Ile Glu Ile Gly Thr Val 790 795 800	2575
55	GGT GGT GGG ACC AAC CTC CTA CCA CAG CAG GCC TGT CTG CAG ATG CTA Gly Gly Gly Thr Asn Leu Leu Pro Gln Gln Ala Cys Leu Gln Met Leu 805 810 815 820	2623
60	GGT GTT CAA CGA CGG TGC AAA GAC AAT CCT GGA GAA AAT GCA CGG CAA Gly Val Gln Gly Ala Cys Lys Asp Asn Pro Gly Glu Asn Ala Arg Gln 825 830 835	2671
65	CTT GCC CGA ATT GTG TGT GGT ACT GTA ATG GCT GGG GAG TTG TCC TTG Leu Ala Arg Ile Val Cys Gly Thr Val Met Ala Gly Glu Leu Ser Leu 840 845 850	2719

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	ATG GCA GCA TTG GCA GCA GGA CAT CTT GTT AGA AGT CAC ATG GTT CAT Met Ala Ala Leu Ala Ala Gly His Leu Val Arg Ser His Met Val His 855 860 865	2767
10	AAC AGA TCG AAG ATA AAT TTA CAA GAT CTG CAA GGA ACG TGC ACC AAG Asn Arg Ser Lys Ile Asn Leu Gln Asp Leu Gln Gly Thr Cys Thr Lys 870 875 880	2815
	AAG TCA GCT TGAGCAGCCT GACAGTATTG AACTGAAACA CGGGCATTGG Lys Ser Ala 885	2864
15	GTTCTCAAGG ACTAACATGA AATCTGTGAA TTAAAAATCT CAATGCAGTG TCTTGTGGAA GATGAATGAA CGTGATCAGT GAGACGCCCTG CTGGGTTCT GGCTCTTCAT GAGACGTCTG AGGTCCCTTG CTCGGAGACT CCTCAGATCT GGAAACAGTG TGGTCCCTCC CATGCTGTAT	2924 2984
20	TCTGAAAAGA TCTCATATGG ATGTTGTGCT CTGACCACCA CAGATGTGAT CTGCAGCTCG TTTCTGAAAT GATGGAGTTTC ATGGTGATCA GTGTGAGACT GGCTCTCCC AGCAGGTTAA AAATGGAGTT TTAAATTATA CTGTAGCTGA CAGTACTTCT GATTTTATAT TTATTTAGTC	3044 3104 3164
25	TGAGTTGTAG AACCTTGCAA TCTAAGTTA TTTTTGTAA CCTAATAATT CATTGGTGC TGGTCTATTG ATTTTGCCCC GTAAACAATA TTATTCTTCAT GAAGGGGACC TACTTCTCA TGGGAAGAAT TACTTTTATT CTCAAACCTAC AGAACAAATGT GCTAAAGCAGT GCTAAATTGT	3224 3284 3344
30	TCTCATGAAG AAAACAGTCA CTGCATTTAT CTCTGTAGGC CTTTTTCAG AGAGGCCCTG TCTAGATTT TGCCAGCTAG GCTACTGCAT GTCTTAGTGT CAGGCCTTAG GAAAGTGCCA CGCTCTGCAC TAAAGATAATC AGAGCTCTG GTGTACTTA GACAAGAGTA TGAGCAAGTC	3404 3464 3524
35	GGACCTCTCA GAGTGTGGGA ACACAGTTTT GAAAGAAAAA CCATTTCTCT AAGCCAATT TCTTTAAAGA CATTTTAACT TATTTAGCTG AGTTCTAGAT TTTTCGGGTA AACTATCAA TCTGTATATG TTGTAATAAA GTGTCTTATG CTAGGAGTTT ATTCAAAGTG TTTAAGTAAT	3644 3704 3764
40	AAAAGGACTC AAATTTACAC TGATAAAAATA CTCTAGCTG GGCCAGAGAA GACAGTGCTC ATTAGCCCTG TCCAGGAAAC CCTGCTTGCT TGCCAAAGCCT AATGAAGGGA AAGTCAGCTT TCAGAGCCAA TGATGGAGGC CACATGAATG GCCCTGGAGC TGTGTGCCTT GTTCTGTGGC	3824 3884 3944
45	CAGGAGCTTG GTGACTGAAT CATTACGGG CTCCCTTGAT GGACCCATAA AAGCTCTTAG CTTCCTCAGG GGGTCAGCAG AGTTGTTGAA TCTTAATTTC TTTTTAAATG TACCAAGTTT	4004 4064

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5 GTATAAATAAA TAATAAAGAG CTCCCTTATTT TGTATTCTAT CTAATGCTTC GAGTTCAGTC 4124
 TTGGGAAGCT GACATCTCAT GTAGAAGATG GACTCTGAAA GACATTCCAA GAGTGCAGCG 4184
 10 GCATCATGGG AGCCCTCTTAG TGATTGTGTC TGACTATTAT TGTGGAAGAT TGACTTTGCT 4244
 TTTGTATGTG AAGTTTCAGA TTGCTCCCTCT TGTGACTTTT TAGCCAGTAA CATTTTATTT 4304
 ACCTGAGCTT GTCATGGAAG TGGCACTGAA AAGTATTGAG TATTCACTGCT GGTGACTGTA 4364
 15 ACCAATGTCA TCTTGCTAAA AACTCATGTT TTGTACAATT ACTAAATTGT ATACATTTG 4424
 TTATAGAATA CTTTTTCCAG TTGAGTAATT TATGAAAGGA AGTTAACATT AACAGGTGTA 4484
 ACCGGTGGCT TTTTTAAAAT GAAGGATTAA CCCTAAGCCC GAGACCCAGA AGCTAGCAA 4544
 20 GTCTGGCAGA GTGGTAAACT GTCTGCTGG GGCCATCCAA TCATCTCTCT CCATTACACT 4604
 TTCTAACTTT GCAGCATTGG TGCTGGCCAG TGTATTGTTT CATTGATCTT CCTTACGCTT 4664
 AGAGGGTTTG ATTGGTTCAG ATCTATAATC TCAGGCCACAT TGTCTGGTA TCAGCTGGAG 4724
 AGAGTTAAGA GGAAGGGAAA ATAAAGTTCA GATAGCCAAA ACAC 4768

25 (2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 887 amino acids
 30 (B) TYPE: amino acid
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

35 Met Leu Ser Arg Leu Phe Arg Met His Gly Leu Phe Val Ala Ser His
 1 5 10 15
 Pro Trp Glu Val Ile Val Gly Thr Val Thr Leu Thr Ile Cys Met Met
 20 25 30
 40 Ser Met Asn Met Phe Thr Gly Asn Asn Lys Ile Cys Gly Trp Asn Tyr
 35 40 45
 Glu Cys Pro Lys Phe Glu Glu Asp Val Leu Ser Ser Asp Ile Ile Ile
 50 55 60
 45 Leu Thr Ile Thr Arg Cys Ile Ala Ile Leu Tyr Ile Tyr Phe Gln Phe
 65 70 75 80

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5 Pro Ile Thr Ser Pro Val Val Thr Pro Lys Lys Ala Pr Asp Asn Cys
 355 360 365
 Cys Arg Arg Glu Pro Leu Leu Val Arg Arg Ser Glu Lys Leu Ser Ser
 370 375 380
 10 Val Glu Glu Glu Pro Gly Val Ser Gln Asp Arg Lys Val Glu Val Ile
 385 390 395 400
 Lys Pro Leu Val Val Glu Thr Glu Ser Ala Ser Arg Ala Thr Phe Val
 405 410 415
 15 Leu Gly Ala Ser Gly Thr Ser Pro Pro Val Ala Ala Arg Thr Gln Glu
 420 425 430
 Leu Glu Ile Glu Leu Pro Ser Glu Pro Arg Pro Asn Glu Glu Cys Leu
 435 440 445
 20 Gln Ile Leu Glu Ser Ala Glu Lys Gly Ala Lys Phe Leu Ser Asp Ala
 450 455 460
 Glu Ile Ile Gln Leu Val Asn Ala Lys His Ile Pro Ala Tyr Lys Leu
 465 470 475 480
 25 Glu Thr Leu Met Glu Thr His Glu Arg Gly Val Ser Ile Arg Arg Gln
 485 490 495
 Leu Leu Ser Thr Lys Leu Pro Glu Pro Ser Ser Leu Gln Tyr Leu Pro
 500 505 510
 30 Tyr Arg Asp Tyr Asn Tyr Ser Leu Val Met Gly Ala Cys Cys Glu Asn
 515 520 525
 Val Ile Gly Tyr Met Pro Ile Pro Val Gly Val Ala Gly Pro Leu Cys
 530 535 540
 Leu Asp Gly Lys Glu Tyr Gln Val Pro Met Ala Thr Thr Glu Gly Cys
 545 550 555 560
 40 Leu Val Ala Ser Thr Asn Arg Gly Cys Arg Ala Ile Gly Leu Gly Gly
 565 570 575
 Gly Ala Ser Ser Arg Val Leu Ala Asp Gly Met Thr Arg Gly Pro Val
 580 585 590
 45 Val Arg Leu Pro Arg Ala Cys Asp Ser Ala Glu Val Lys Ala Trp Leu
 595 600 605
 Glu Thr Pro Glu Gly Phe Ala Val Ile Lys Asp Ala Phe Asp Ser Thr
 610 615 620

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5 Ser Arg Phe Ala Arg Leu Gln Lys Leu His Val Thr Met Ala Gly Arg
 625 630 635 640

 Asn Leu Tyr Ile Arg Phe Gln Ser Lys Thr Gly Asp Ala Met Gly Met
 645 650 655

 10 Asn Met Ile Ser Lys Gly Thr Glu Lys Ala Leu Leu Lys Leu Gln Glu
 660 665 670

 Phe Phe Pro Glu Met Gln Ile Leu Ala Val Ser Gly Asn Tyr Cys Thr
 675 680 685

 15 Asp Lys Lys Pro Ala Ala Ile Asn Trp Ile Glu Gly Arg Gly Lys Thr
 690 695 700

 Val Val Cys Glu Ala Val Ile Pro Ala Lys Val Val Arg Glu Val Leu
 705 710 715 720

 20 Lys Thr Thr Thr Glu Ala Met Ile Asp Val Asn Ile Asn Lys Asn Leu
 725 730 735

 Val Gly Ser Ala Met Ala Gly Ser Ile Gly Gly Tyr Asn Ala His Ala
 740 745 750

 25 Ala Asn Ile Val Thr Ala Ile Tyr Ile Ala Cys Gly Gln Asp Ala Ala
 755 760 765

 Gln Asn Val Gly Ser Ser Asn Cys Ile Thr Leu Met Glu Ala Ser Gly
 770 775 780

 30 Pro Thr Asn Glu Asp Leu Tyr Ile Ser Cys Thr Met Pro Ser Ile Glu
 785 790 795 800

 Ile Gly Thr Val Gly Gly Thr Asn Leu Leu Pro Gln Gln Ala Cys
 805 810 815

 35 Leu Gln Met Leu Gly Val Gln Gly Ala Cys Lys Asp Asn Pro Gly Glu
 820 825 830

 Asn Ala Arg Gln Leu Ala Arg Ile Val Cys Gly Thr Val Met Ala Gly
 835 840 845

 40 Glu Leu Ser Leu Met Ala Ala Leu Ala Ala Gly His Leu Val Arg Ser
 850 855 860

 His Met Val His Asn Arg Ser Lys Ile Asn Leu Gln Asp Leu Gln Gly
 865 870 875 880

 45 Thr Cys Thr Lys Lys Ser Ala
 885

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(2) INFORMATION FOR SEQ ID NO:5:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 3348 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

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(ii) MOLECULE TYPE: DNA (genomic)

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(ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 121..3255

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(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

GGAATATTTT GTACGAGCAA GTTATAGTAA GACACITTCAG TGAGAAATTAA ATCTGACTTA	60
CTTTTACTTA ATTGTGTCT TTCCAAATTAA GTTCAACAAG GTTCCCACAT ACAACCTCAA	120
ATG TCA CTT CCC TTA AAA ACG ATA GTA CAT TTG GTA AAG CCC TTT GCT	168
Met Ser Leu Pro Leu Lys Thr Ile Val His Leu Val Lys Pro Phe Ala	
1 5 10 15	
TGC ACT GCT AGG TTT AGT GCG AGA TAC CCA ATC CAC GTC ATT GTT GTT	216
Cys Thr Ala Arg Phe Ser Ala Arg Tyr Pro Ile His Val Ile Val Val	
20 25 30	
GCT GTT TTA TTG AGT GCC GCT GCT TAT CTA TCC GTG ACA CAA TCT TAC	264
Ala Val Leu Leu Ser Ala Ala Tyr Leu Ser Val Thr Gln Ser Tyr	
35 40 45	
CTT AAC GAA TGG AAG CTG GAC TCT AAT CAG TAT TCT ACA TAC TTA AGC	312
Leu Asn Glu Trp Lys Leu Asp Ser Asn Gln Tyr Ser Thr Tyr Leu Ser	
50 55 60	
ATA AAG CCG GAT GAG TTG TTT GAA AAA TGC ACA CAC TAC TAT AGG TCT	360
Ile Lys Pro Asp Glu Leu Phe Glu Lys Cys Thr His Tyr Tyr Arg Ser	
65 70 75 80	
CCT GTG TCT GAT ACA TGG AAG TTA CTC AGC TCT AAA GAA GCC GCC GAT	408
Pro Val Ser Asp Thr Trp Lys Leu Leu Ser Ser Lys Glu Ala Ala Asp	
85 90 95	
ATT TAT ACC CCT TTT CAT TAT TAT TTG TCT ACC ATA AGT TTT CAA AGT	456
Ile Tyr Thr Pro Phe His Tyr Tyr Leu Ser Thr Ile Ser Phe Gln Ser	
100 105 110	

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	AAG GAC AAT TCA ACG ACT TTG CCT TCC CTT GAT GAC GTT ATT TAC AGT Lys Asp Asn Ser Thr Thr Leu Pro Ser Leu Asp Asp Val Ile Tyr Ser 115 120 125	504
10	GTT GAC CAT ACC AGG TAC TTA TTA AGT GAA GAG CCA AAG ATA CCA ACT Val Asp His Thr Arg Tyr Leu Leu Ser Glu Glu Pro Lys Ile Pro Thr 130 135 140	552
15	GAA CTA GTG TCT GAA AAC GGA ACG AAA TGG AGA TTG AGA AAC AAC AGC Glu Leu Val Ser Glu Asn Gly Thr Lys Trp Arg Leu Arg Asn Asn Ser 145 150 155 160	600
20	AAT TTT ATT TTG GAC CTG CAT AAT ATT TAC CGA AAT ATG GTG AAG CAA Asn Phe Ile Leu Asp Leu His Asn Ile Tyr Arg Asn Met Val Lys Gln 165 170 175	648
25	TTT TCT AAC AAA ACG AGC GAA TTT GAT CAG TTC GAT TTG TTT ATC ATC Phe Ser Asn Lys Thr Ser Glu Phe Asp Gln Phe Asp Leu Phe Ile Ile 180 185 190	696
30	CTA GCT GCT TAC CTT ACT CTT TTT TAT ACT CTC TGT TGC CTG TTT AAT Leu Ala Ala Tyr Leu Thr Leu Phe Tyr Thr Leu Cys Cys Leu Phe Asn 195 200 205	744
35	GAC ATG AGG AAA ATC GGA TCA AAG TTT TGG TTA AGC TTT TCT GCT CTT Asp Met Arg Lys Ile Gly Ser Lys Phe Trp Leu Ser Phe Ser Ala Leu 210 215 220	792
40	TCA AAC TCT GCA TGC GCA TTA TAT TTA TCG CTC TAC ACA ACT CAC AGT Ser Asn Ser Ala Cys Ala Leu Tyr Leu Ser Leu Tyr Thr Thr His Ser 225 230 235 240	840
45	TTA TTG AAG AAA CCG GCT TCC TTA AGT TTG GTC ATT GGA CTA CCA Leu Leu Lys Lys Pro Ala Ser Leu Leu Ser Leu Val Ile Gly Leu Pro 245 250 255	888
50	TTT ATC GTA GTA ATT ATT GGC TTT AAG CAT AAA GTT CGA CTT GCG GCA Phe Ile Val Val Ile Ile Gly Phe Lys His Lys Val Arg Leu Ala Ala 260 265 270	936
55	TTC TCG CTA CAA AAA TTC CAC AGA ATT AGT ATT GAC AAG AAA ATA ACG Phe Ser Leu Gln Lys Phe His Arg Ile Ser Ile Asp Lys Lys Ile Thr 275 280 285	984
60	GTA AGC AAC ATT ATT TAT GAG GCT ATG TTT CAA GAA GGT GCC TAC TTA Val Ser Asn Ile Ile Tyr Glu Ala Met Phe Gln Glu Gly Ala Tyr Leu 290 295 300	1032
65	ATC CGC GAC TAC TTA TTT TAT ATT AGC TCC TTC ATT GGA TGT GCT ATT Ile Arg Asp Tyr Leu Phe Tyr Ile Ser Ser Phe Ile Gly Cys Ala Ile 305 310 315 320	1080

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	TAT GCT AGA CAT CTT CCC GGA TTG GTC AAT TTC TGT ATT TTG TCT ACA Tyr Ala Arg His Leu Pro Gly Leu Val Asn Phe Cys Ile Leu Ser Thr 325 330 335	1128
10	TTT ATG CTA GTT TTC GAC TTG CTT TTG TCT GCT ACT TTT TAT TCT GCC Phe Met Leu Val Phe Asp Leu Leu Ser Ala Thr Phe Tyr Ser Ala 340 345 350	1176
15	ATT TTA TCA ATG AAC CTG GAA ATT AAC ATC ATT CAC AGA TCA ACC GTC Ile Leu Ser Met Lys Leu Glu Ile Asn Ile Ile His Arg Ser Thr Val 355 360 365	1224
20	ATC AGA CAG ACT TTG GAA GAG GAC GGA GTC CCA ACT ACA GCA GAT Ile Arg Gln Thr Leu Glu Asp Gly Val Val Pro Thr Thr Ala Asp 370 375 380	1272
25	ATT ATA TAT AAC GAT GAA ACT GCC TCA GAA CCA CAT TTT TTG AGA TCT Ile Ile Tyr Lys Asp Glu Thr Ala Ser Glu Pro His Phe Leu Arg Ser 385 390 395 400	1320
30	AAC GTG GCT ATC ATT CTG GGA AAA GCA TCA GTT ATT GGT CTT TTG CTT Asn Val Ala Ile Ile Leu Gly Lys Ala Ser Val Ile Gly Leu Leu 405 410 415	1368
35	CTG ATC AAC CTT TAT GTT TTC ACA GAT AAG TTA AAT GCT ACA ATA CTA Leu Ile Asn Leu Tyr Val Phe Thr Asp Lys Leu Asn Ala Thr Ile Leu 420 425 430	1416
40	AAC ACC GCA TAT TTT GAC TCT ACA ATT TAC TCG TTA CCA AAT TTT ATC Asn Thr Val Tyr Phe Asp Ser Thr Ile Tyr Ser Leu Pro Asn Phe Ile 435 440 445	1464
45	AAT TAT AAA GAT ATT GGC AAT CTC AGC AAT CAA GTG ATC ATT TCC GTG Asn Tyr Lys Asp Ile Gly Asn Leu Ser Asn Gln Val Ile Ile Ser Val 450 455 460	1512
50	TTG CCA AAG CAA TAT TAT ACT CCG CTG AAA AAA TAC CAT CAG ATC GAA Leu Pro Lys Gln Tyr Tyr Thr Pro Leu Lys Tyr His Gln Ile Glu 465 470 475 480	1560
55	GAT TCT GTT CTA CTT ATC ATT GAT TCC GTT AGC AAT GCT ATT CGG GAC Asp Ser Val Leu Leu Ile Ile Asp Ser Val Ser Asn Ala Ile Arg Asp 485 490 495	1608
60	CAA TTT ATC AGC AAG TTA CTT TTT GCA TTT GCA GTT AGT ATT TCC Gln Phe Ile Ser Lys Leu Leu Phe Phe Ala Phe Ala Val Ser Ile Ser 500 505 510	1656
65	ATC AAT GTC TAC TTA CTG AAT GCT GCA AAA ATT CAC ACA GGA TAC ATG Ile Asn Val Tyr Leu Leu Asn Ala Ala Lys Ile His Thr Gly Tyr Met 515 520 525	1704

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	AAC TTC CAA CCA CAA TCA AAT AAG ATC GAT GAT CTT GTT GTT CAG CAA Asn Phe Gln Pro Gln Ser Asn Lys Ile Asp Asp Leu Val Val Gln Gln 530 535 540	1752
10	AAA TCG GCA ACG ATT GAG TTT TCA GAA ACT CGA AGT ATG CCT GCT TCT Lys Ser Ala Thr Ile Glu Phe Ser Glu Thr Arg Ser Met Pro Ala Ser 545 550 555 560	1800
15	TCT GCC CTA GAA ACT CCA GTG ACC GCG AAA GAT ATA ATT ATC TCT GAA Ser Gly Leu Glu Thr Pro Val Thr Ala Lys Asp Ile Ile Ser Glu 565 570 575	1848
	GAA ATC CAG AAT AAC GAA TGC GTC TAT GCT TTG AGT TCC CAG GAC GAG Glu Ile Gln Asn Asn Glu Cys Val Tyr Ala Leu Ser Ser Gln Asp Glu 580 585 590	1896
20	CCT ATC CGT CCT TTA TCG AAT TTA GTG GAA CTT ATG GAG AAA GAA CAA Pro Ile Arg Pro Leu Ser Asn Leu Val Glu Leu Met Glu Lys Glu Gln 595 600 605	1944
	TTA AAG AAC ATG AAT AAT ACT GAG GTT TCG AAT CTT GTC GTC AAC GGT Leu Lys Asn Met Asn Asn Thr Glu Val Ser Asn Leu Val Val Asn Gly 610 615 620	1992
25	AAA CTG CCA TTA TAT TCC TTA GAG AAA AAA TTA GAG GAC ACA ACT CGT Lys Leu Pro Leu Tyr Ser Leu Glu Lys Lys Leu Glu Asp Thr Thr Arg 625 630 635 640	2040
30	GCG GTT TTA GTT AGG AGA AAG GCA CTT TCA ACT TTG GCT GAA TCG CCA Ala Val Leu Val Arg Arg Lys Ala Leu Ser Thr Leu Ala Glu Ser Pro 645 650 655	2088
	ATT TTA GTT TCC GAA AAA TTG CCC TTC AGA AAT TAT GAT TAT GAT CGC Ile Leu Val Ser Glu Lys Leu Pro Phe Arg Asn Tyr Asp Tyr Asp Arg 660 665 670	2136
35	GTT TTT GGA GCT TGC TGT GAA AAT GTC ATC GGC TAT ATG CCA ATA CCA Val Phe Gly Ala Cys Cys Glu Asn Val Ile Gly Tyr Met Pro Ile Pro 675 680 685	2184
40	GTT GGT GTA ATT GGT CCA TTA ATT ATT GAT GGA ACA TCT TAT CAC ATA Val Gly Val Ile Gly Pro Leu Ile Ile Asp Gly Thr Ser Tyr His Ile 690 695 700	2232
	CCA ATG GCA ACC ACG GAA GGT TGT TTA GTG GCT TCA GCT ATG CGT GGT Pro Met Ala Thr Thr Glu Gly Cys Leu Val Ala Ser Ala Met Arg Gly 705 710 715 720	2280
45	TGC AAA GCC ATC AAT GCT GGT GGT GCA ACA ACT GTT TTA ACC AAA Cys Lys Ala Ile Asn Ala Gly Gly Ala Thr Thr Val Leu Thr Lys 725 730 735	2328

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	GAT GGT ATG ACT AGA GGC CCA GTC GTT CGT TTC CCT ACT TTA ATA AGA Asp Gly Met Thr Arg Gly Pro Val Val Arg Phe Pro Thr Leu Ile Arg 740 745 750	2376
10	TCT GGT GCC TGC AAG ATA TCG TTA GAC TCG GAA GAG GGA CAA AAT TCA Ser Gly Ala Cys Lys Ile Trp Leu Asp Ser Glu Glu Gly Gln Asn Ser 755 760 765	2424
15	ATT AAA AAA GCT TTT AAT TCT ACA TCA AGG TTT GCA CGT TTG CAA CAT Ile Lys Lys Ala Phe Asn Ser Thr Ser Arg Phe Ala Arg Leu Gln His 770 775 780	2472
	ATT CAA ACC TGT CTA GCA GGC GAT TTG CTT TTT ATG AGA TTT CGG ACA Ile Gln Thr Cys Leu Ala Gly Asp Leu Leu Phe Met Arg Phe Arg Thr 785 790 795 800	2520
20	ACT ACC GGT GAC GCA ATG GGT ATG AAC ATG ATA TCG AAA GGT GTC GAA Thr Thr Gly Asp Ala Met Gly Met Asn Met Ile Ser Lys Gly Val Glu 805 810 815	2568
	TAC TCT TTG AAA CAA ATG GTA GAA GAA TAT GGT TGG GAA GAT ATG GAA Tyr Ser Leu Lys Gln Met Val Glu Glu Tyr Gly Trp Glu Asp Met Glu 820 825 830	2616
25	GTT GTC TCC GTA TCT GGT AAC TAT TGT ACT GAT AAG AAA CCT GCC GCA Val Val Ser Val Ser Gly Asn Tyr Cys Thr Asp Lys Lys Pro Ala Ala 835 840 845	2664
30	ATC AAT TCG ATT GAA GGT CGT GGT AAA AGT GTC GTA GCT GAA GCT ACT Ile Asn Trp Ile Glu Gly Arg Gly Lys Ser Val Val Ala Glu Ala Thr 850 855 860	2712
	ATT CCT GGT GAT GTC GTA AAA AGT GTT TTA AAG AGC GAT GTT TCC GCT Ile Pro Gly Asp Val Val Lys Ser Val Leu Lys Ser Asp Val Ser Ala 865 870 875 880	2760
35	TTA GTT GAA TTA AAT ATA TCC AAG AAC TTG GTT GGA TCC GCA ATG GCT Leu Val Glu Leu Asn Ile Ser Lys Asn Leu Val Gly Ser Ala Met Ala 885 890 895	2808
40	GGA TCT GTT GGT GGT TTC AAC GCG CAC GCA GCT AAT TTG GTC ACT GCA Gly Ser Val Gly Gly Phe Asn Ala His Ala Ala Asn Leu Val Thr Ala 900 905 910	2856
	CTT TTC TTG GCA TTA GGC CAA GAT CCT GCG CAG AAC GTC GAA AGT TCC Leu Phe Leu Ala Leu Gly Gln Asp Pro Ala Gln Asn Val Glu Ser Ser 915 920 925	2904
45	AAC TGT ATA ACT TTG ATG AAG GAA GTT GAT GGT GAT TTA AGG ATC TCT Asn Cys Ile Thr Leu Met Lys Glu Val Asp Gly Asp Leu Arg Ile Ser 930 935 940	2952

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	GTT TCC ATG CCA TCT ATT GAA GTT GGT ACG ATT GGC GGG GGT ACT GTT Val Ser Met Pro Ser Ile Glu Val Gly Thr Ile Gly Gly Thr Val 945 950 955 960	3000
10	CTG GAG CCT CAG GGC GCC ATG CTT GAT CTT CTC GGC GTT CGT GGT CCT Leu Glu Pro Gln Gly Ala Met Leu Asp Leu Leu Gly Val Arg Gly Pro 965 970 975	3048
	CAC CCC ACT GAA CCT GGA GCA AAT GCT AGG CAA TTA GCT AGA ATA ATC His Pro Thr Glu Pro Gly Ala Asn Ala Arg Gln Leu Ala Arg Ile Ile 980 985 990	3096
15	GCG TGT GCT GTC TTG GCT GGT GAA CTG TCT CTG TGC TCC GCA CTT GCT Ala Cys Ala Val Leu Ala Gly Glu Leu Ser Leu Cys Ser Ala Leu Ala 995 1000 1005	3144
20	GCC GGT CAC CTG GTA CAA AGC CAT ATG ACT CAC AAC CGT AAA ACA AAC Ala Gly His Leu Val Gln Ser His Met Thr His Asn Arg Lys Thr Asn 1010 1015 1020	3192
	AAA GCC AAT GAA CTG CCA CAA CCA AGT AAC AAA GGG CCC CCC TGT AAA Lys Ala Asn Glu Leu Pro Gln Pro Ser Asn Lys Gly Pro Pro Cys Lys 1025 1030 1035 1040	3240
25	ACC TCA GCA TTA TTA TAACTCTTGT AGTTTACATG GTGATACTTT ATATCTTTGT Thr Ser Ala Leu Leu 1045	3295
	ATTGTCTAGC TATTCTAAAT CATCTGCATG TAATAAGAAG TTGATCAAAA TGA	3348
30	(2) INFORMATION FOR SEQ ID NO:6:	

	(i) SEQUENCE CHARACTERISTICS: (A) LENGTH: 1045 amino acids (B) TYPE: amino acid (C) TOPOLOGY: linear
35	(ii) MOLECULE TYPE: protein
	(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:
40	Met Ser Leu Pro Leu Lys Thr Ile Val His Leu Val Lys Pro Phe Ala 1 5 10 15
	Cys Thr Ala Arg Phe Ser Ala Arg Tyr Pro Ile His Val Ile Val Val 20 25 30
45	Ala Val Leu Leu Ser Ala Ala Tyr Leu Ser Val Thr Gln Ser Tyr 35 40 45

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5 Tyr Ala Arg His Leu Pro Gly Leu Val Asn Phe Cys Ile Leu Ser Thr
 325 330 335
 Phe Met Leu Val Phe Asp Leu Leu Leu Ser Ala Thr Phe Tyr Ser Ala
 340 345 350
 10 Ile Leu Ser Met Lys Leu Glu Ile Asn Ile Ile His Arg Ser Thr Val
 355 360 365
 Ile Arg Gln Thr Leu Glu Glu Asp Gly Val Val Pro Thr Thr Ala Asp
 370 375 380
 15 Ile Ile Tyr Lys Asp Glu Thr Ala Ser Glu Pro His Phe Leu Arg Ser
 385 390 395 400
 Asn Val Ala Ile Ile Leu Gly Lys Ala Ser Val Ile Gly Leu Leu
 405 410 415
 20 Leu Ile Asn Leu Tyr Val Phe Thr Asp Lys Leu Asn Ala Thr Ile Leu
 420 425 430
 Asn Thr Val Tyr Phe Asp Ser Thr Ile Tyr Ser Leu Pro Asn Phe Ile
 435 440 445
 25 Asn Tyr Lys Asp Ile Gly Asn Leu Ser Asn Gln Val Ile Ile Ser Val
 450 455 460
 Leu Pro Lys Gln Tyr Tyr Thr Pro Leu Lys Lys Tyr His Gln Ile Glu
 465 470 475 480
 30 Asp Ser Val Leu Leu Ile Ile Asp Ser Val Ser Asn Ala Ile Arg Asp
 485 490 495
 Gln Phe Ile Ser Lys Leu Leu Phe Phe Ala Phe Ala Val Ser Ile Ser
 500 505 510
 Ile Asn Val Tyr Leu Leu Asn Ala Ala Lys Ile His Thr Gly Tyr Met
 515 520 525
 35 Asn Phe Gln Pro Gln Ser Asn Lys Ile Asp Asp Leu Val Val Gln Gln
 530 535 540
 Lys Ser Ala Thr Ile Glu Phe Ser Glu Thr Arg Ser Met Pro Ala Ser
 545 550 555 560
 40 Ser Gly Leu Glu Thr Pro Val Thr Ala Lys Asp Ile Ile Ile Ser Glu
 565 570 575
 Glu Ile Gln Asn Asn Glu Cys Val Tyr Ala Leu Ser Ser Gln Asp Glu
 580 585 590
 45
 50

5 Pro Ile Arg Pr Leu Ser Asn Leu Val Glu Leu Met Glu Lys Glu Gln
 595 600 605
 Leu Lys Asn Met Asn Asn Thr Glu Val Ser Asn Leu Val Val Asn Gly
 610 615 620
 10 Lys Leu Pro Leu Tyr Ser Leu Glu Lys Lys Leu Glu Asp Thr Thr Arg
 625 630 635 640
 Ala Val Leu Val Arg Arg Lys Ala Leu Ser Thr Leu Ala Glu Ser Pro
 645 650 655
 15 Ile Leu Val Ser Glu Lys Leu Pro Phe Arg Asn Tyr Asp Tyr Asp Arg
 660 665 670
 Val Phe Gly Ala Cys Cys Glu Asn Val Ile Gly Tyr Met Pro Ile Pro
 675 680 685
 20 Val Gly Val Ile Gly Pro Leu Ile Ile Asp Gly Thr Ser Tyr His Ile
 690 695 700
 Pro Met Ala Thr Thr Glu Gly Cys Leu Val Ala Ser Ala Met Arg Gly
 705 710 715 720
 25 Cys Lys Ala Ile Asn Ala Gly Gly Ala Thr Thr Val Leu Thr Lys
 725 730 735
 Asp Gly Met Thr Arg Gly Pro Val Val Arg Phe Pro Thr Leu Ile Arg
 740 745 750
 30 Ser Gly Ala Cys Lys Ile Trp Leu Asp Ser Glu Glu Gly Gln Asn Ser
 755 760 765
 Ile Lys Lys Ala Phe Asn Ser Thr Ser Arg Phe Ala Arg Leu Gln His
 35 770 775 780
 Ile Gln Thr Cys Leu Ala Gly Asp Leu Leu Phe Met Arg Phe Arg Thr
 785 790 795 800
 40 Thr Thr Gly Asp Ala Met Gly Met Asn Met Ile Ser Lys Gly Val Glu
 805 810 815
 Tyr Ser Leu Lys Gln Met Val Glu Glu Tyr Gly Trp Glu Asp Met Glu
 820 825 830
 45 Val Val Ser Val Ser Gly Asn Tyr Cys Thr Asp Lys Lys Pro Ala Ala
 835 840 845
 Ile Asn Trp Ile Glu Gly Arg Gly Lys Ser Val Val Ala Glu Ala Thr
 850 855 860
 50

5 Ile Pro Gly Asp Val Val Lys Ser Val Leu Lys Ser Asp Val Ser Ala
 865 870 875 880
 Leu Val Glu Leu Asn Ile Ser Lys Asn Leu Val Gly Ser Ala Met Ala
 885 890 895
 10 Gly Ser Val Gly Gly Phe Asn Ala His Ala Ala Asn Leu Val Thr Ala
 900 905 910
 Leu Phe Leu Ala Leu Gly Gln Asp Pro Ala Gln Asn Val Glu Ser Ser
 915 920 925
 15 Asn Cys Ile Thr Leu Met Lys Glu Val Asp Gly Asp Leu Arg Ile Ser
 930 935 940
 Val Ser Met Pro Ser Ile Glu Val Gly Thr Ile Gly Gly Gly Thr Val
 945 950 955 960
 20 Leu Glu Pro Gln Gly Ala Met Leu Asp Leu Leu Gly Val Arg Gly Pro
 965 970 975
 His Pro Thr Glu Pro Gly Ala Asn Ala Arg Gln Leu Ala Arg Ile Ile
 980 985 990
 25 Ala Cys Ala Val Leu Ala Gly Glu Leu Ser Leu Cys Ser Ala Leu Ala
 995 1000 1005
 Ala Gly His Leu Val Gln Ser His Met Thr His Asn Arg Lys Thr Asn
 1010 1015 1020
 30 Lys Ala Asn Glu Leu Pro Gln Pro Ser Asn Lys Gly Pro Pro Cys Lys
 1025 1030 1035 1040
 Thr Ser Ala Leu Leu
 1045
 35 (2) INFORMATION FOR SEQ ID NO:7:

(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 22 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

45

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

GATCCGTCGA CGCATGCCTG CA

• 50

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5

(2) INFORMATION FOR SEQ ID NO:8:

- 10 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 14 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

15

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

GGCATGCGTC GACG

14

20 (2) INFORMATION FOR SEQ ID NO:9:

- 25 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 10 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

30

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

CCGGATCCGG

10

(2) INFORMATION FOR SEQ ID NO:10:

- 35 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 33 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

40

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

AGCTTTCGCG AGCTCGAGAT CTAGATATCG ATG

33

(2) INFORMATION FOR SEQ ID NO:11:

- 45 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 32 base pairs

50

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- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

10 (ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

15 AATTCAATCGA TATCTAGATC TCGAGCTCGC GA

32

(2) INFORMATION FOR SEQ ID NO:12:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 24 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

20 (ii) MOLECULE TYPE: DNA (genomic)

25 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

TATCGAATT C AAGCTTGGTA CGGA

24

(2) INFORMATION FOR SEQ ID NO:13:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 24 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

35 (ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

TATCGGTACC AAGCTTGAAT TCGA

24

40 (2) INFORMATION FOR SEQ ID NO:14:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 15 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

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(ii) MOLECULE TYPE: DNA (genomic)

10 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

GATCCAGCTG TGTAC

15

(2) INFORMATION FOR SEQ ID NO:15:

- 15 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 17 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

20

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

CCCGGGATCG ATCACGT

17

25 (2) INFORMATION FOR SEQ ID NO:16

- 30 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 17 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

35 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

GATCGATCCC GGGACGT

17

(2) INFORMATION FOR SEQ ID NO:17:

- 40 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

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(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

10 ATAAAGACAT TGTTTTAGA TCTGTTGTAA

30

(2) INFORMATION FOR SEQ ID NO:18:

- (1) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 32 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

20 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

GATTATCTT CGTTTCCTGC AAGTTTTGCT TC

32

(2) INFORMATION FOR SEQ ID NO:19:

- (1) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 35 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

30

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

ACCTTCGAAG AACGAAGGAA GGAGCACAGA CTTAG

35

35 (2) INFORMATION FOR SEQ ID NO:20:

- (1) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 34 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

40 (ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

45 ATGGTATAT ATACGCATAT TGCGGCCCG GTAC

34

60

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(2) INFORMATION FOR SEQ ID NO:21:

10

- (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 26 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

15

- (ii) MOLECULE TYPE: DNA (genomic)

16

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:

CGCGGGCCGCA ATATGCCGTAT ATATAAC

26

20

(2) INFORMATION FOR SEQ ID NO:22:

25

- (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 35 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: DNA (genomic)

30

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:

CAATCTAAGT CTGTGCTCCT TCCTTCGTTTC TTGGA

35

35

(2) INFORMATION FOR SEQ ID NO:23:

40

- (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: DNA (genomic)

45

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:

CTTTATGAGG GTAACATGAA TTCAGAGAAGG

30

45

(2) INFORMATION FOR SEQ ID NO:24:

- (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs

50

55

5 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: single
 (D) TOPOLOGY: linear

10 (ii) MOLECULE TYPE: DNA (genomic)

15 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:

10 GCCAAGTAGT TTTTACTCTT CAAGACAGAT AATTTCGCTGA CA

42

15 Claims

- 20 1. A method of increasing squalene, zymosterol, cholesta-7,24-dienol and cholesta-5,7,24-trienol accumulation in yeast comprising increasing the expression level of a structural gene encoding a polypeptide having HMG-CoA reductase activity in a mutant yeast having defects in the expression of zymosterol-24-methyltransferase and ergosta-5,7,24(28)-trienol-22-dehydrogenase.
- 25 2. The method according to claim 1 wherein said encoded polypeptide is an active, truncated HMG-CoA reductase enzyme.
- 30 3. The method according to claim 1 wherein said polypeptide is an active, truncated HMG-CoA reductase enzyme comprising the catalytic and at least a portion of the linker region but is free from the membrane binding region of S. cerevisiae HMG-CoA reductase #1.
- 35 4. The method according to claim 1 wherein said structural gene encodes an active, truncated HMG-CoA reductase enzyme comprising the catalytic and at least a portion of the linker region that is free from the membrane binding region of an HMG-CoA reductase enzyme.
- 40 5. The method according to claim 1 wherein the yeast is of the species S. cerevisiae.
- 45 6. The method according to claim 1 wherein squalene is accumulated relative to said zymosterol, cholesta-7,24-dienol and cholesta-5,7,24-trienol by culturing said yeast under conditions of restricted aeration.
- 50 7. The method according to claim 1 wherein the expression level is increased by increasing the copy number of a structural gene encoding a polypeptide having HMG-CoA reductase activity.
- 55 8. The method according to claim 7 wherein the copy number is increased by transforming said yeast with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes a polypeptide having HMG-CoA reductase activity, and a promoter suitable for driving the expression of said polypeptide in said yeast.
- 60 9. The method according to claim 8 wherein the promoter is selected from the group consisting of the GAL 1, GAL 10, GAL 1-10, PGK and ADH promoters.
- 65 10. The method according to claim 8 wherein the promoter and the exogenous DNA segment are integrated into the chromosomal DNA of said yeast.
- 70 11. A method of increasing squalene, ergosta-8,22-dienol, ergosta-7,22 dienol, ergosta-8-enol and ergosta-7-enol accumulation in yeast of the species S. cerevisiae comprising transforming a mutant S. cerevisiae having a defect in the expression of episterol-5-dehydrogenase with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes the catalytic region and at least a portion of the linker region but is free from the membrane binding region of an HMG-CoA reductase enzyme, and a promoter suitable for driving the expression of said reductase in said yeast.

12. A method of increasing squalene, zymosterol and cholesta-7,24-dienol accumulation in yeast of the species S. cerevisiae comprising transforming a mutant S. cerevisiae having a defect in the expression of zymosterol-24-methyltransferase and episterol-5-dehydrogenase with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes the catalytic region and at least a portion of the linker region but is free from the membrane binding region of an HMG-CoA reductase enzyme, and a promoter suitable for driving the expression of said reductase in said yeast.
13. A method of increasing squalene, zymosterol, ergosta-5,7,24(28)-triol and ergosta-5,7-dienol accumulation in yeast of the species S. cerevisiae comprising transforming a mutant S. cerevisiae having a defect in the expression of ergosta-5,7,24(28)-triol-22-dehydrogenase with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes the catalytic region and at least a portion of the linker region but is free from the membrane binding region of an HMG-CoA reductase enzyme, and a promoter suitable for driving the expression of said reductase in said yeast.
14. The method according to claim 11, 12 or 13 wherein the recombinant DNA molecule is selected from the group of plasmid vectors consisting of plasmids pSOC725ARC, pSOC106ARC, pARC300D, pARC306E, pARC300S, pARC300T and pARC304S.
15. A mutant S. cerevisiae having defects in the expression of zymosterol-24-methyltransferase and ergosta-5,7,24(28)-triol-22-dehydrogenase enzymes, which mutant species is designated ATC0402mu.
16. A mutant of S. cerevisiae having single or double defects in the expression of enzymes that catalyze the conversion of squalene to ergosterol transformed with a recombinant DNA molecule comprising a vector operatively linked to an exogenous DNA segment that encodes the catalytic region and at least a portion of the linker region but is free from the membrane binding region of an HMG-CoA reductase enzyme, and a promoter suitable for driving the expression of said reductase in said yeast.
17. The mutant according to claim 16 wherein the mutant is selected from the group consisting of mutants ATC0315rc, ATC1500, ATC1502, ATC1503, ATC1551, ATC2100, ATC2104, ACT2107, ACT2108, ATC2109 and ATC2401.
18. A recombinant DNA molecule selected from the group of plasmids designated plasmids pARC304S, pARC300S, pARC300T, pARC300D, pARC306E, pSOC106ARC and pSOC725ARC.

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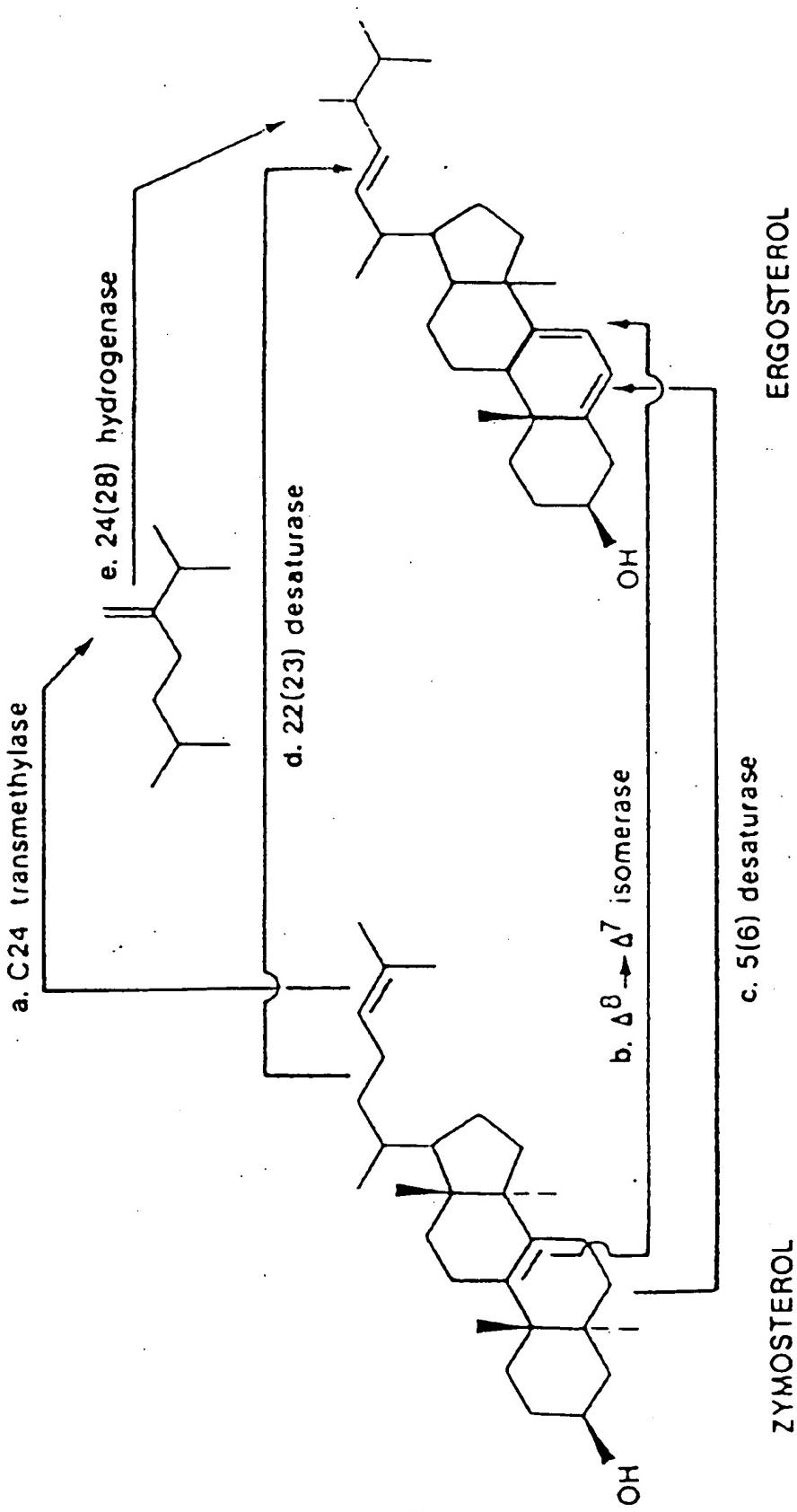


FIGURE 1

TTTATTAACT TATTTTTTC TTCTTTCTAC CCAATTCTAG	TCAGGAAAG ACTAAGGGCT	60
GGAACATAGT GTATCATGT CTAATTGTTG ATACAAAGTA	GATAAATACA TAAACAAAGC	120
ATG CCG CCG CTA TTC AAG GGA CTG AAA CAG ATG GCA AAG CCA ATT GCC		168
Met Pro Pro Leu Phe Lys Gly Leu Lys Gln Met Ala Lys Pro Ile Ala		
1 5 10 15		
TAT GTT TCA AGA TTT TCG GCG AAA CGA CCA ATT CAT ATA CTT TTT		216
Tyr Val Ser Arg Phe Ser Ala Lys Arg Pro Ile His Ile Ile Leu Phe		
20 25		
TCT CTA ATC ATA TCC GCA TTC GCT TAT CTA TCC GTC ATT CAG TAT TAC		264
Ser Leu Ile Ile Ser Ala Phe Ala Tyr Leu Ser Val Ile Gln Tyr Tyr		
35 40 45		
TTC AAT GGT TGG CAA CTA GAT TCA AAT AGT GTT TTT GAA ACT GCT CCA		312
Phe Asn Gly Trp Gln Leu Asp Ser Asn Ser Val Phe Glu Thr Ala Pro		
50 55 60		
AAT AAA GAC TCC AAC ACT CTA TTT CAA GAA TGT TCC CAT TAC TAC AGA		360
Asn Lys Asp Ser Asn Thr Leu Phe Gln Glu Cys Ser His Tyr Tyr Arg		
65 70 75 80		

GAT	TCC	TCT	CTA	GAT	GGT	TGG	GTA	TCA	ATC	ACC	GCG	CAT	GAA	GCT	AGT	408
Asp	Ser	Ser	Leu	Asp	Gly	Trp	Val	Ser	Ile	Thr	Ala	His	Glu	Ala	Ser	
																95
																90
GAG	TTA	CCA	GCC	CCA	CAC	CAT	TAC	TAT	CTA	TTA	AAC	CTG	AAC	TTC	AAT	456
Glu	Leu	Pro	Ala	Pro	His	His	Tyr	Tyr	Leu	Leu	Asn	Leu	Asn	Phe	Asn	
																110
																105
AGT	CCT	AAT	GAA	ACT	GAC	TCC	ATT	CCA	GAA	CTA	GCT	AAC	ACG	GTT	TTT	504
Ser	Pro	Asn	Glu	Thr	Asp	Ser	Ile	Pro	Glu	Leu	Ala	Asn	Thr	Val	Phe	
																125
																120
GAG	AAA	GAT	AAT	ACA	AAA	TAT	ATT	CTG	CAA	GAA	GAT	CTC	AGT	GTT	TCC	552
Glu	Lys	Asp	Asn	Thr	Lys	Tyr	Ile	Leu	Gln	Glu	Asp	Leu	Ser	Val	Ser	
																140
																135
AAA	GAA	ATT	TCT	TCT	ACT	GAT	GGA	ACG	AAA	TGG	AGG	TTA	AGA	AGT	GAC	600
Lys	Glu	Ile	Ser	Ser	Thr	Asp	Gly	Thr	Lys	Trp	Arg	Leu	Arg	Ser	Asp	
																155
																150
AGA	AAA	AGT	CTT	TTC	GAC	GTA	AAG	ACG	TTA	GCA	TAT	TCT	CTC	TAC	GAT	648
Arg	Lys	Ser	Leu	Phe	Asp	Val	Lys	Thr	Leu	Ala	Tyr	Ser	Leu	Tyr	Asp	
																175
																165
																170

FIGURE 2-2

GTA	TTT	TCA	GAA	AAT	GTA	ACC	CAA	GCA	GAC	CCG	TTT	GAC	GTC	CTT	ATT	696
Val	Phe	Ser	Glu	Asn	Val	Thr	Gln	Ala	Asp	Pro	Phe	Asp	Val	Leu	Ile	
180								185					190			
ATG	GTT	ACT	GCC	TAC	CTA	ATG	ATG	TTC	TAC	ACC	ATA	TTC	GGC	CTC	TC	744
Met	Val	Thr	Ala	Tyr	Leu	Met	Met	Phe	Tyr	Thr	Ile	Phe	Gly	Leu	Phe	
195								200					205			
AAT	GAC	ATG	AGG	AAG	ACC	GGG	TCA	AAT	TTT	TGG	TTG	AGC	GCC	TCT	ACA	792
Asn	Asp	Met	Arg	Lys	Thr	Gly	Ser	Asn	Phe	Trp	Leu	Ser	Ala	Ser	Thr	
210								215					220			
GTG	GTC	AAT	TCT	GCA	TCA	TCA	CTT	TTC	TTA	GCA	TTC	TAT	GTC	ACC	CAA	840
Val	Val	Asn	Ser	Ala	Ser	Ser	Leu	Phe	Leu	Ala	Leu	Tyr	Val	Thr	Gln	
225								230					235			240
TGT	ATT	CTA	GGC	AAA	GAA	GTT	TCC	GCA	TTA	ACT	CTT	TTT	GAA	GGT	TTG	888
Cys	Ile	Leu	Gly	Lys	Glu	Vai	Ser	Ala	Leu	Thr	Leu	Phe	Glu	Gly	Leu	
								245					250			255
CCT	TTC	ATT	GTA	GTT	GTT	GTT	GGT	TTC	AAG	CAC	AAA	ATC	AAG	ATT	GCC	936
Pro	Phe	Ile	Val	Val	Vai	Vai	Gly	Phe	Lys	His	Lys	Ile	Lys	Ile	Ala	
								260					265			270

FIGURE 2-3

CAG	TAT	GCC	CTG	GAG	AAA	TTT	GAA	AGA	GTC	GGT	TTA	TCT	AAA	AGG	ATT	984
Gln	Tyr	Ala	Leu	Glu	Lys	Phe	Glu	Arg	Val	Gly	Leu	Ser	Lys	Arg	Ile	285
																275
ACT	ACC	GAT	GAA	ATC	GTG	TTT	GAA	TCC	GTG	AGC	GAA	GAG	GGT	GGT	CGT	1032
Thr	Thr	Asp	Glu	Ile	Val	Phe	Glu	Ser	Val	Ser	Glu	Glu	Gly	Gly	Arg	290
																290
TTG	ATT	CAA	GAC	CAT	TTG	CTT	TGT	ATT	TTT	GCC	TTT	ATC	GGA	TGC	TCT	1080
Leu	Ile	Gln	Asp	His	Leu	Leu	Cys	Ile	Phe	Ala	Phe	Ile	Gly	Cys	Ser	320
																305
ATG	TAT	GCT	CAC	CAA	TTG	AAG	ACT	TTG	ACA	AAC	TTC	TGC	ATA	TTA	TCA	1128
Met	Tyr	Ala	His	Gln	Leu	Lys	Thr	Leu	Thr	Asn	Phe	Cys	Ile	Leu	Ser	335
																325
GCA	TTT	ATC	CTA	ATT	TTT	GAA	TTG	ATT	TTA	ACT	CCT	ACA	TTT	TAT	TCT	1176
Ala	Phe	Ile	Leu	Ile	Phe	Glu	Leu	Ile	Leu	Thr	Pro	Thr	Phe	Tyr	Ser	350
																340
GCT	ATC	TTA	GCG	CTT	AGA	CTG	GAA	ATG	AAT	GTT	ATC	CAC	AGA	TCT	ACT	1224
Ala	Ile	Leu	Ala	Leu	Arg	Leu	Glu	Met	Asn	Val	Ile	His	Arg	Ser	Thr	365
																355

FIGURE 2-4

ATT ATC AAG CAA ACA TTA GAA GAC GGT GTT CCA TCT ACA GCA	1272
Ile Ile Lys Gln Thr Leu Glu Glu Asp Gly Val Val Pro Ser Thr Ala	
370 375 380	
AGA ATC ATT TCT AAA GCA GAA AAG AAA TCC GTA TCT TCT TTC TTA AAT	1320
Arg Ile Ile Ser Lys Ala Glu Lys Lys Ser Val Ser Ser Phe Leu Asn	
385 390 395 400	
CTC AGT GTG GTT GTC ATT ATC ATG AAA CTC TCT GTC ATA CTG TTG TTT	1368
Leu Ser Val Val Ile Ile Met Lys Leu Ser Val Ile Leu Leu Phe	
405 410 415	
GTT TTC ATC AAC TTT TAT AAC TTT GGT GCA AAT TGG GTC AAT GAT GCC	1416
Val Phe Ile Asn Phe Tyr Asn Phe Gly Ala Asn Trp Val Asn Asp Ala	
420 425 430	
TTC AAT TCA TTG TAC TTC GAT AAG GAA CGT GTT TCT CTA CCA GAT TTT	1464
Phe Asn Ser Leu Tyr Phe Asp Lys Glu Arg Val Ser Leu Pro Asp Phe	
435 440 445	
ATT ACC TCG AAT GCC TCT GAA AAC TTT AAA GAG CAA GCT ATT GTT AGT	1512
Ile Thr Ser Asn Ala Ser Glu Asn Phe Lys Glu Gln Ala Ile Val Ser	
450 455 460	

FIGURE 2-5

GTC	ACC	CCA	TTA	TTA	TAT	TAC	AAA	CCC	ATT	AAG	TCC	TAC	CAA	CGC	ATT	1560
Val	Thr	Pro	Leu	Leu	Tyr	Tyr	Lys	Pro	Ile	Lys	Ser	Tyr	Gln	Arg	Ile	
465																480
GAG	GAT	ATG	GTT	CTT	CTA	TTG	CTT	CGT	AAT	GTC	AGT	GTT	GCC	ATT	CGT	1608
Glu	Asp	Met	Val	Leu	Leu	Leu	Leu	Arg	Asn	Val	Ser	Val	Ala	Ile	Arg	
																495
GAT	AGG	TTC	GTC	AGT	AAA	TTA	GTT	CTT	TCC	GCC	TTA	GTA	TGC	AGT	GCT	1656
Asp	Arg	Phe	Val	Ser	Lys	Leu	Val	Leu	Ser	Ala	Leu	Val	Cys	Ser	Ala	
																500
GTC	ATC	AAT	GTG	TAT	TTA	TTG	AAT	GCT	GCT	AGA	ATT	CAT	ACC	AGT	TAT	1704
Val	Ile	Asn	Val	Tyr	Leu	Leu	Asn	Ala	Ala	Arg	Ile	His	Thr	Ser	Tyr	
																515
ACT	GCA	GAC	CAA	TTG	GTG	AAA	ACT	GAA	GTC	ACC	AAG	TCT	TTT	ACT	1752	
Thr	Ala	Asp	Gln	Leu	Val	Lys	Thr	Glu	Val	Thr	Lys	Ser	Phe	Thr		
																530
GCT	CCT	GTA	CAA	AAG	GCT	TCT	ACA	CCA	GTT	TTA	ACC	AAT	AAA	ACA	GTC	1800
Ala	Pro	Val	Gln	Lys	Ala	Ser	Thr	Pro	Val	Leu	Thr	Asn	Lys	Thr	Val	
																545
																555
																560

FIGURE 2-6

ATT	TCT	GGA	TCG	AAA	GTC	AAA	AGT	TTA	TCA	TCT	GCG	CAA	TCG	AGC	TCA	1848
Ile	Ser	Gly	Ser	Lys	Val	Lys	Ser	Leu	Ser	Ala	Gln	Ser	Ser	Ser	Ser	
																565
																570
																575
TCA	GGA	CCT	TCA	TCA	TCT	AGT	GAG	GAA	GAT	GAT	TCC	CGC	GAT	ATT	GAA	1896
Ser	Gly	Pro	Ser	Ser	Ser	Ser	Glu	Glu	Asp	Asp	Ser	Arg	Asp	Ile	Glu	
																580
																585
																590
AGC	TTG	GAT	AAG	AAA	ATA	CGT	CCT	TTA	GAA	GAA	TTA	GAA	GCA	TTA	TTA	1944
Ser	Leu	Asp	Lys	Lys	Ile	Arg	Pro	Leu	Glu	Glu	Leu	Glu	Ala	Leu	Leu	
																595
																600
																605
AGT	AGT	GGA	AAT	ACA	AAA	CAA	TTG	AAG	AAC	AAA	GAG	GTC	GCT	GCC	TTG	1992
Ser	Ser	Gly	Asn	Thr	Lys	Gln	Leu	Lys	Asn	Lys	Glu	Val	Ala	Ala	Leu	
																610
																615
																620
GTT	ATT	CAC	GGT	AAG	TTA	CCT	TTG	TAC	GCT	TTG	GAG	AAA	AAA	TTA	GGT	2040
Val	Ile	Ile	His	Gly	Lys	Leu	Pro	Leu	Tyr	Ala	Leu	Glu	Lys	Lys	Leu	
																625
																630
																635
GAT	ACT	ACG	AGA	GCG	GTT	GCG	GTA	CGT	AGG	AAG	GCT	CTT	TCA	ATT	TTG	2088
Asp	Thr	Thr	Arg	Ala	Val	Ala	Val	Arg	Arg	Lys	Ala	Leu	Ser	Ile	Leu	
																645
																650
																655

FIGURE 2-7

GCA	GAA	GCT	CCT	GTA	TTC	GCA	TCT	GAT	CGT	TTA	CCA	TAT	AAA	AAT	TAT	2136
Ala	Glu	Ala	Pro	Val	Leu	Ala	Ser	Asp	Arg	Leu	Pro	Tyr	Lys	Asn	Tyr	
660																665
GAC	TAC	GAC	CGC	GTA	TTT	GGC	GCT	TGT	TGT	GAA	AAT	GTT	ATA	GGT	TAC	2184
Asp	Tyr	Asp	Arg	Val	Phe	Gly	Ala	Cys	Cys	Glu	Asn	Val	Ile	Gly	Tyr	
675																680
ATG	CCT	TTG	CCC	GTT	GGT	GTA	GGC	CCC	TTG	GTT	ATC	GAT	GGT	ACA	2232	
Met	Pro	Leu	Pro	Val	Gly	Val	Ile	Gly	Pro	Leu	Val	Ile	Asp	Gly	Thr	
690																695
TCT	TAT	CAT	ATA	CCA	ATG	GCA	ACT	ACA	GAG	GGT	TGT	TTG	GCT	TCT	2280	
Ser	Tyr	His	Ile	Pro	Met	Ala	Thr	Thr	Glu	Gly	Cys	Leu	Val	Ala	Ser	
705																710
GCC	ATG	CGT	GGC	TGT	AAG	GCA	ATC	AAT	GCT	GGC	GGT	GCA	ACA	ACT	2328	
Ala	Met	Arg	Gly	Cys	Lys	Ala	Ile	Asn	Ala	Gly	Gly	Ala	Thr	Thr		
																725
GTT	TTA	ACT	AAG	GAT	GGT	ATG	ACA	AGA	GGC	CCA	GTA	GTC	CGT	TTC	CCA	2376
Val	Leu	Thr	Lys	Asp	Gly	Met	Thr	Arg	Gly	Pro	Val	Val	Arg	Phe	Pro	
740																745
																750

FIGURE 2-8

ACT TTG AAA AGA TCT GGT GCC TGT	AAG ATA TGG TTA GAC TCA GAA GAG	2424
Thr Leu Lys Arg Ser Gly Ala Cys Lys Ile Trp Leu Asp Ser Glu Glu		
755	760	765
GGA CAA AAC GCA ATT AAA GCT TTT AAC TCT ACA TCA AGA TTT GCA		2472
Gly Gln Asn Ala Ile Lys Lys Ala Phe Asn Ser Thr Ser Arg Phe Ala		
770	775	780
CGT CTG CAA CAT ATT CAA ACT TGT CTA GCA GGA GAT TTA CRC TTC ATG		2520
Arg Leu Gln His Ile Gln Thr Cys Leu Ala Gly Asp Leu Phe Met		
785	790	795
72 AGA TTT AGA ACA ACT ACT GGT GAC GCA ATG GGT ATG AAT ATG ATT TCT		2568
Arg Phe Arg Thr Thr Gly Asp Ala Met Gly Met Asn Met Ile Ser		
805	810	815
AAA GGT GTC GAA TAC TCA TTA AAG CAA ATG GTA GAA GAG TAT GGC TGG		2616
Lys Gly Val Glu Tyr Ser Leu Lys Gln Met Val Glu Glu Tyr Gly Trp		
820	825	830
GAA GAT ATG GAG GTT GTC TCC GTT TCT GGT AAC TAC TGT ACC GAC AAA		2664
Glu Asp Met Glu Val Val Ser Val Ser Gly Asn Tyr Cys Thr Asp Lys		
835	840	845

FIGURE 2-9

AAA	CCA	GCT	GCC	ATC	AAC	TGG	ATC	GAA	GCT	CGT	GGT	AAG	AGT	GTC	GTC	2712
Lys	Pro	Ala	Ala	Ile	Asn	Trp	Ile	Glu	Gly	Arg	Gly	Lys	Ser	Val	Val	
																850
																855
																860
GCA	GAA	GCT	ACT	ATT	CCT	GGT	GAT	GTT	GTC	AGA	AAA	GTG	TTA	AAA	AGT	2760
Ala	Glu	Ala	Thr	Ile	Pro	Gly	Asp	Val	Val	Arg	Lys	Val	Leu	Lys	Ser	
																865
																870
GAT	GTT	TCC	GCA	TTG	GAG	TTG	AAC	ATT	GCT	AAG	AAT	TTG	TTG	GGA	2808	
Asp	Val	Ser	Ala	Leu	Val	Glu	Leu	Asn	Ile	Ala	Lys	Asn	Leu	Val	Gly	
																885
																890
TCT	GCA	ATG	GCT	GGG	TCT	GGT	GGG	TTT	AAC	GCA	CAT	GCA	GCT	AAT	2856	
Ser	Ala	Met	Ala	Gly	Ser	Val	Gly	Gly	Phe	Asn	Ala	His	Ala	Ala	Asn	
																900
																905
TTA	GTG	ACA	GCT	GTT	TTG	GCA	TTA	GGA	CAA	GAT	CCT	GCA	CAA	AAT	2904	
Ileu	Vai	Thr	Ala	Val	Phe	Leu	Ala	Leu	Gly	Gln	Asp	Pro	Ala	Gln	Asn	
																915
																920
GTT	GAA	AGT	TCC	AAC	TGT	ATA	ACA	TTG	ATG	AAA	GAA	GTG	GAC	GGT	GAT	2952
Val	Glu	Ser	Ser	Asn	Cys	Ile	Thr	Leu	Met	Lys	Glu	Val	Asp	Gly	Asp	
																930
																935
																940

FIGURE 2-10

TTG	AGA	ATT	TCC	GTA	TCC	ATG	CCA	TCC	ATC	GAA	GTA	GGT	ACC	ATC	GGT	3000
Leu	Arg	Ile	Ser	Val	Ser	Met	Pro	Ser	Ile	Glu	Val	Gly	Thr	Ile	Gly	
945																960
950																
GCT	GGT	ACT	GTT	CTA	GAA	CCA	CAA	GGT	GCC	ATG	TTG	GAC	TTA	TTA	GGT	3048
Gly	Gly	Gly	Thr	Val	Leu	Glu	Pro	Gln	Gly	Ala	Met	Leu	Asp	Leu	Gly	
965																975
970																
GTA	AGA	GGC	CCG	CAT	GCT	ACC	GCT	CCT	GGT	ACC	AAC	GCA	CGT	CAA	TTA	3096
Val	Arg	Gly	Pro	His	Ala	Thr	Ala	Pro	Gly	Thr	Asn	Ala	Arg	Gln	Leu	
980																990
985																
GCA	AGA	ATA	GTT	GCC	TGT	GCC	GTC	TTC	GCA	GGT	GAA	TTA	TCC	TTA	TGT	3144
Ala	Arg	Ile	Val	Ala	Cys	Ala	Val	Leu	Ala	Gly	Glu	Leu	Ser	Leu	Cys	
995																1005
1000																
GCT	GCC	CTA	GCA	GCC	GGC	CAT	TTC	GTT	CAA	AGT	CAT	ATG	ACC	CAC	AAC	3192
Ala	Ala	Leu	Ala	Ala	Gly	His	Leu	Val	Gln	Ser	His	Met	Thr	His	Asn	
1010																1020
1015																
AGG	AAA	CCT	GCT	GAA	CCA	ACA	AAA	CCT	AAC	AAT	TTG	GAC	GCC	ACT	GAT	3240
Arg	Lys	Pro	Ala	Glu	Pro	Thr	Lys	Pro	Asn	Asn	Leu	Asp	Ala	Thr	Asp	
1025																1035
1030																1040
1035																

FIGURE 2-11

ATA AAT CGT TTG AAA GAT GGG TCC GTC ACC TGC ATT AAA TCC
Ile Asn Arg Leu Lys Asp Gly Ser Val Thr Cys Ile Lys Ser
1045 1050

TAAACTAGT CATACTCAT TGGTATTCTC TTGAAAGA AGCACACAG CACCATGTGT 3342

TACGTAATAATTACTT 3360

FIGURE 2-12

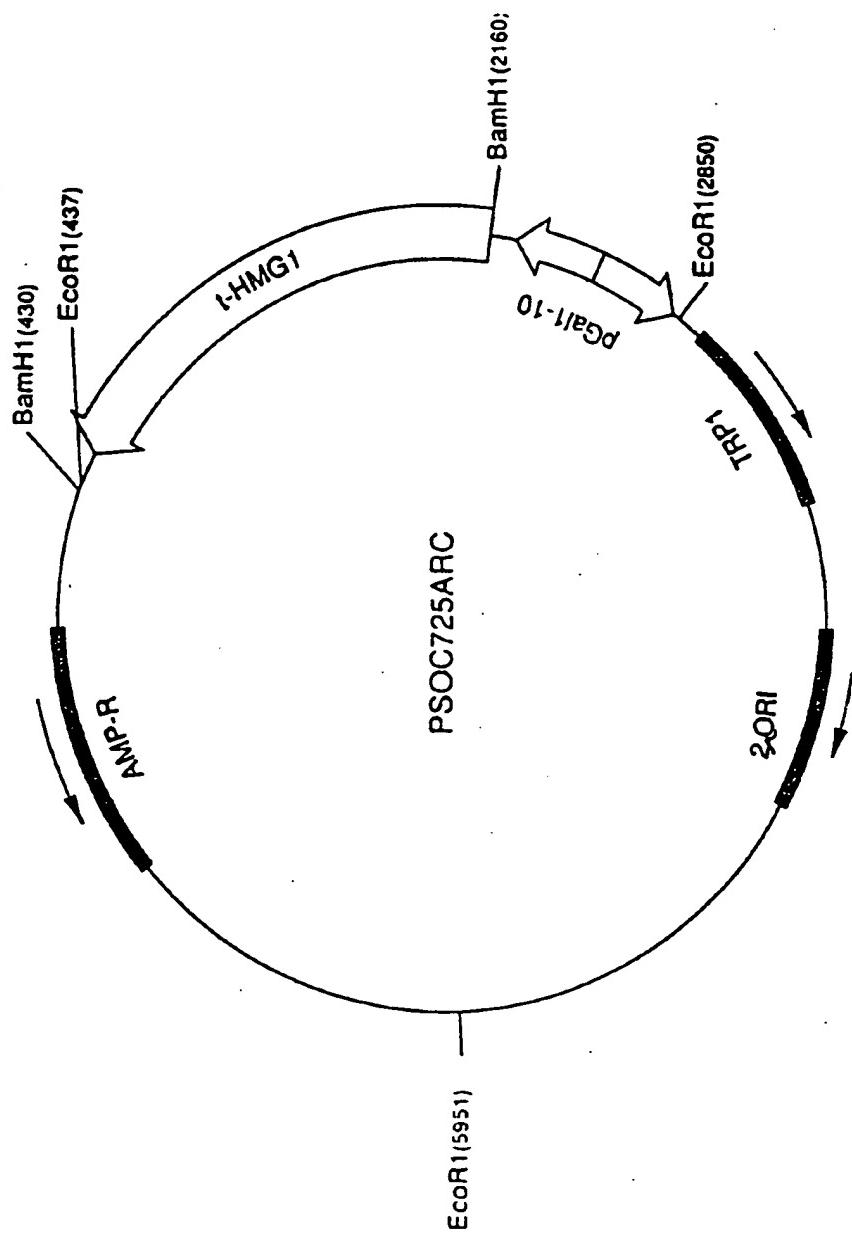


FIGURE 3

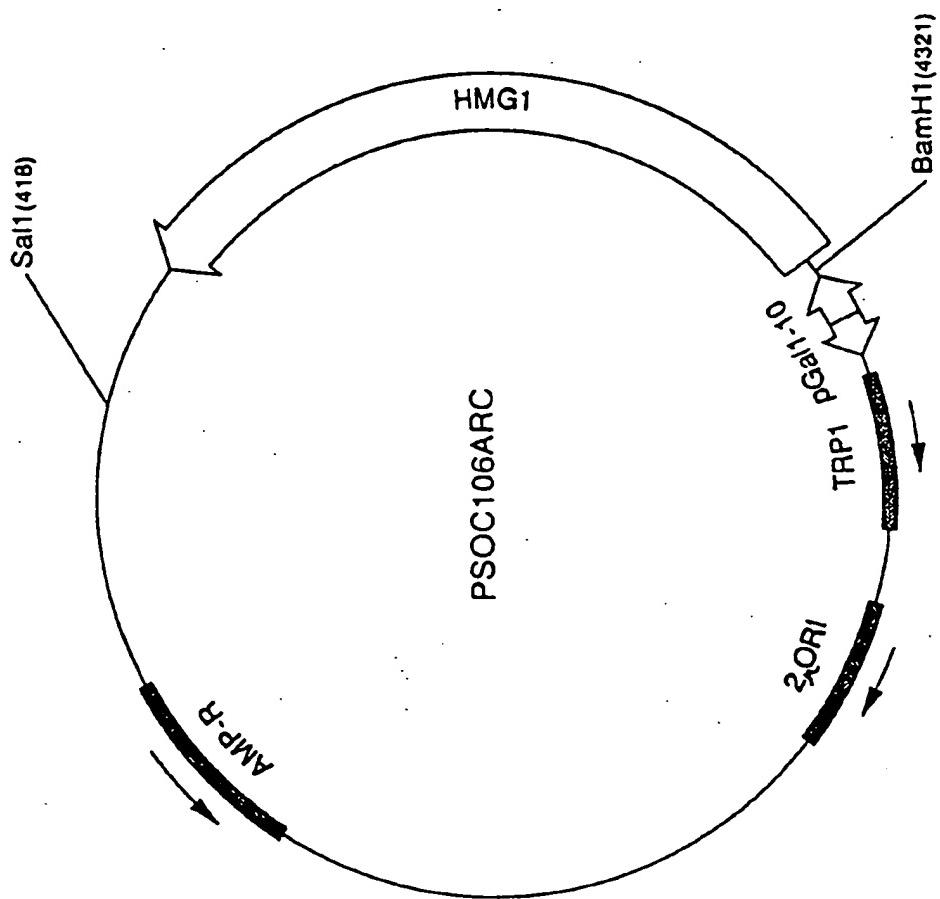


FIGURE 4

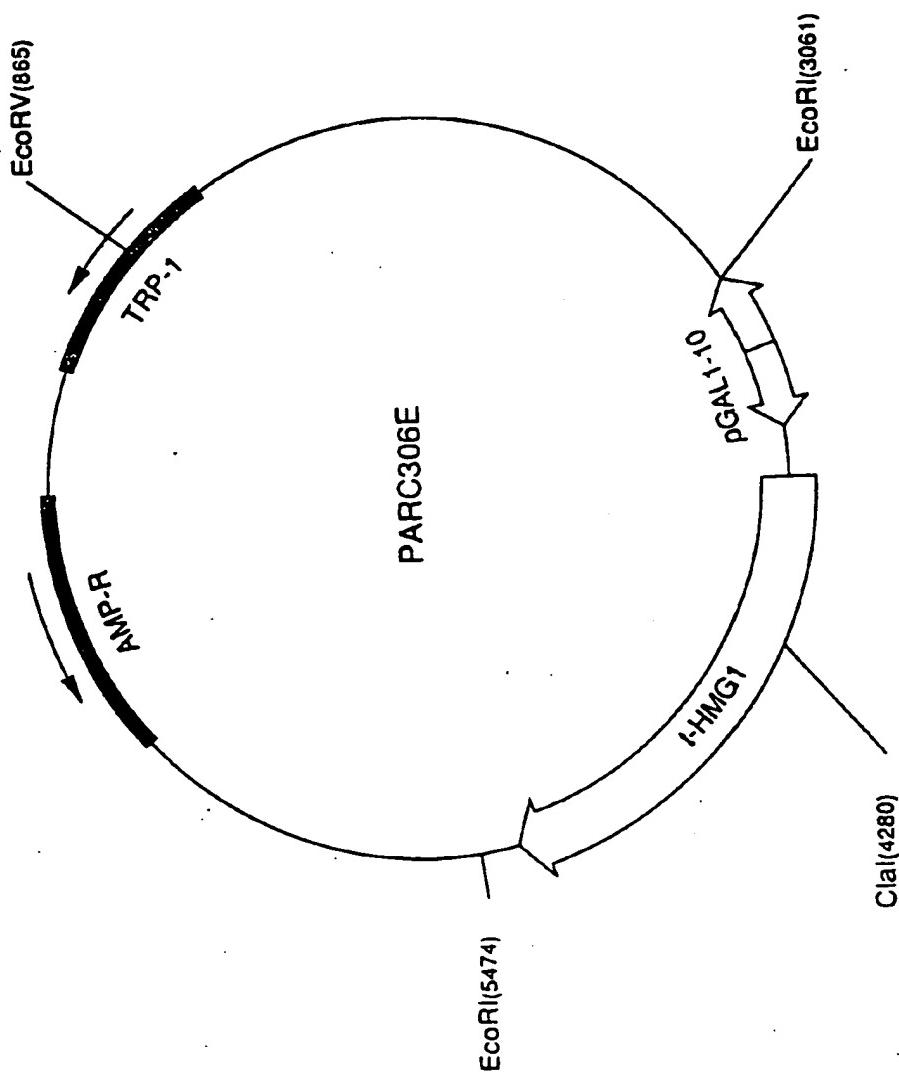


FIGURE 5

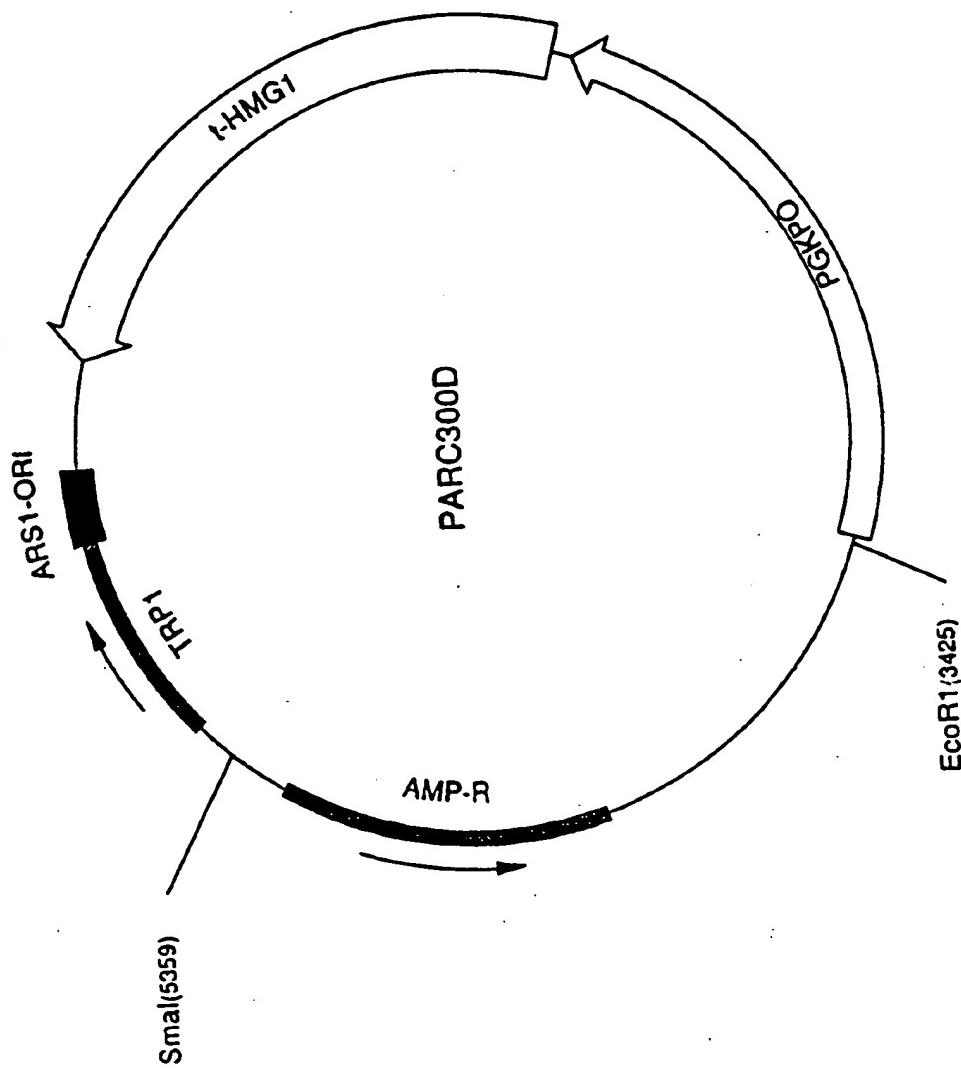


FIGURE 6

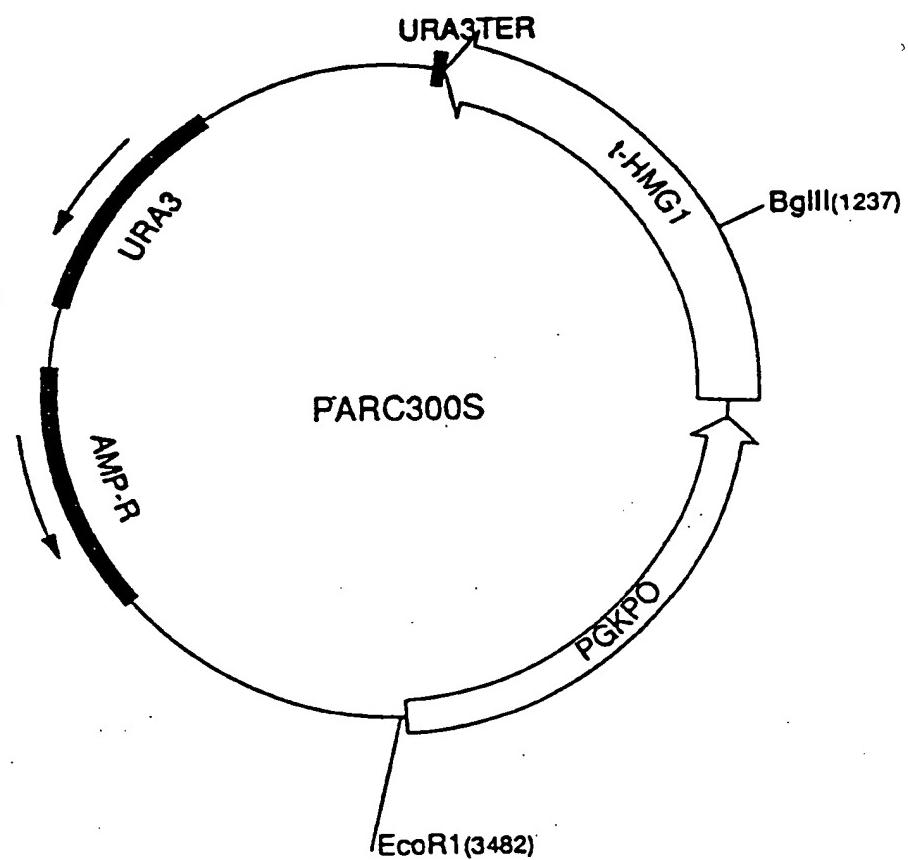


FIGURE 7

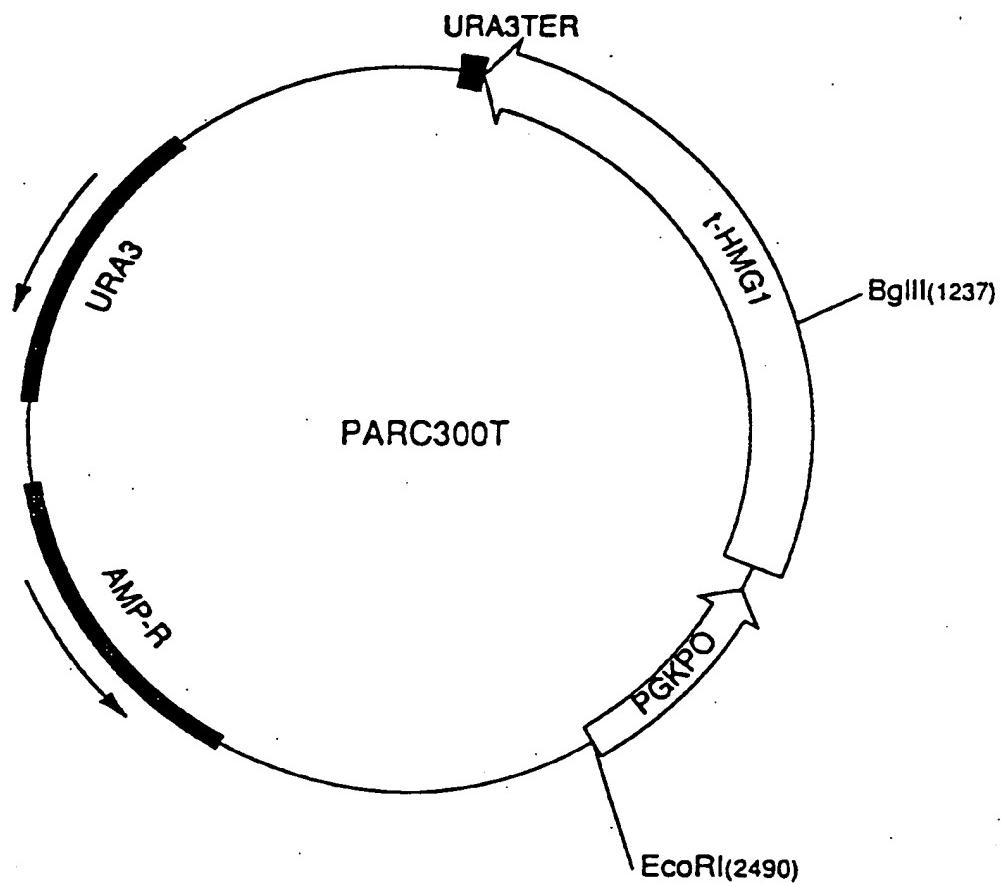


FIGURE 8

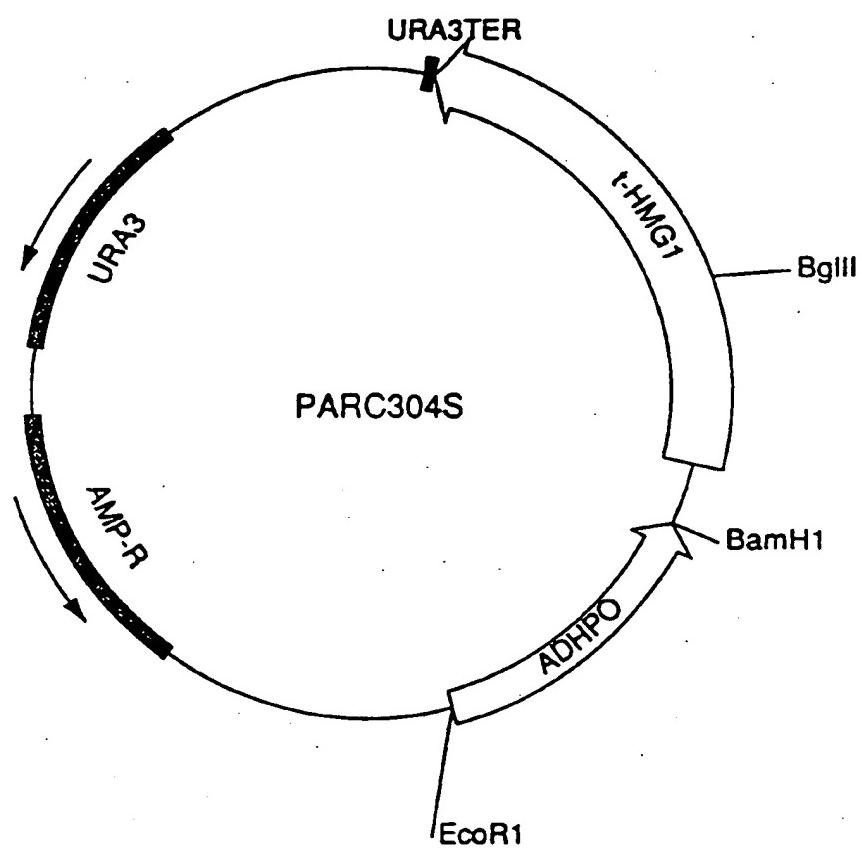


FIGURE 9